City of Cambridge Water Department
2001 Source Water Resources Assessment

July 2003

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Executive Summary

This report presents the results of an ongoing study conducted by the City of Cambridge, Massachusetts Water Department to assess reservoir and tributary-stream quality in the Cambridge drinking-water source area and to use the information gained to help guide watershed management practices. Assessments of the quality and trophic state of the three primary storage reservoirs, Hobbs Brook Reservoir, Stony Brook Reservoir, and Fresh Pond, were conducted to provide baseline information on the state of these resources and to determine the vulnerability of the reservoirs to increased loads of nutrients and other contaminants. The effects of land use, land cover, and other drainage-basin characteristics on sources, transport, and fate of fecal-indicator bacteria; roadway deicing chemicals; nutrients; selected metals; and naturally occurring organic compounds in 11 subbasins that contribute water to the reservoirs also was investigated, and the data used in comparison to the 1998 USGS study to determine long-term trends in water quality and overall effectiveness of watershed management practices.

Water quality in the reservoir system was generally lower in the upper basin of Hobbs Brook Reservoir, and improved as it flowed through the system via Stony Brook Reservoir in Weston to Fresh Pond, in Cambridge. The highest sodium and chloride concentrations were measured in Hobbs Brook Reservoir, which is influenced by runoff from Route 2 and Interstate – 95. Stony Brook Reservoir and its watershed is less influenced by state and local roadways, and exhibited lower sodium, chloride, and nutrient concentrations than those measured in Hobbs Brook Reservoir. The quality of water at the intake to the treatment plant in Fresh Pond was high throughout the study period. Analytical results of samples collected in Fresh Pond yielded consistently low concentrations of nutrients and selected total metals, with manganese, sodium, chloride being the most abundant of the constituents sampled.

Hobbs Brook, Stony Brook, and Fresh Pond Reservoirs met Class "A" Surface Water Standards in Massachusetts for all parameters except for fecal coliform bacteria. Fresh Pond exceeded the State standard (100 cfu/100 ml) only on March 14, and July 17, 2001. All three reservoirs exhibited thermal and chemical stratification, despite artificial mixing by air hoses in Stony Brook Reservoir and Fresh Pond. The stratification produced anoxic or hypoxic conditions in the deepest parts of all the reservoirs and these conditions resulted in the release of ammonia nitrogen, orthophosphate phosphorus, and dissolved iron and manganese from the reservoir bed sediments. Concentrations of sodium and chloride in the reservoirs usually were higher than the amounts recommended by the U.S. environmental Protection agency for drinking-water sources. Maximum measured sodium concentrations were highest in Hobbs Brook Reservoir and Stony Brook Reservoirs, and lowest in Fresh Pond.

Trophic state indices (TSI), indicated that the upper and middle basins of Hobbs Brook Reservoir were moderately to highly productive and likely to produce algal blooms; the lower basin of Hobbs Brook Reservoir and Stony Brook Reservoir were similar and intermediate in productivity, and Fresh Pond was relatively unproductive and unlikely to produce algal blooms. This pattern is likely due to the content of organic carbon and phosphorus in the bed sediments of the three basins of Hobbs Brook Reservoir and in Stony Brook Reservoir.

Hobbs Brook and Stony Brook, the two principle streams draining the Cambridge drinking-water source area, differed in their relative contributions of many of the estimated constituent instantaneous yields (mg/km^2). The estimated instantaneous yield of fecal coliform bacteria was greatest for Stony Brook at Route 20 which drains approximately 41% of the source water area and integrates Hobbs Brook and Stony Brook subbasins. The State standard concentration for fecal coliform bacteria in streams in the Cambridge drinking-water source area (100 cfu/100ml) was exceeded on at least one occasion at all tributary sampling stations during the study period.

Estimated subbasin instantaneous yields for sodium and chloride were significantly correlated with the percentage of the subbasin area occupied by roads, indicating that the application of sodium chloride in road salt is a significant source of sodium measured in the reservoirs. The estimated annual median yields of sodium in the Hobbs Brook subbasin were about four times greater than those produced by the Stony Brook subbasin at the confluence of the two brooks near Kendal Green. The largest instantaneous median sodium yield was at station 4455 that drains a highly developed portion of the Stony Brook Subbasin with a value greater than 1500 mg/km^2.

Estimated yields for total nitrogen were slightly higher in the Stony Brook sub-basin than in that of Hobbs Brook. The highest measured instantaneous nitrogen concentration was at station 4455 just as the case for sodium above. The estimated median instantaneous manganese yield from the Hobbs Brook subbasin was over twice that of the Stony Brook subbasin measured at the confluence near Kendal Green. Estimated annual mean yields for manganese were greatest at station 4410 upstream of the Hobbs Brook Reservoir, and station 4455, a tributary to Stony Brook.

The mass balance for water in Hobbs Brook Reservoir indicated that the time required for complete flushing of the reservoir during water year 2001 was approximately 10 months. The reservoir retained much of the sodium, chloride, nitrogen and phosphorus from the tributary streams and discharges from Routes 2 and 128. Waterfowl and precipitation were insignificant as sources of nitrogen to the reservoir but may have been important as sources of phosphorus. The estimated detention time of Stony Brook Reservoir in 2001 was approximately 10 days, with a total output to the Charles River at an estimated 6.4 billion gallons during the study period. The detention time for Fresh Pond during this period was approximately 6 months.

Introduction

This annual report describes the results of water-quality monitoring efforts during 2000-2001, as part of a long-term on-going study of the health and overall state of the City of Cambridge's drinking water supply. The water-quality monitoring program was designed by the U.S. Geological Survey (USGS), in cooperation with the Cambridge Water Department (CWD), and is based in part on the results of a recent (1998) assessment of reservoir and tributary-stream quality. The assessment, which was conducted jointly by the USGS and the CWD, included a detailed analysis of the drainage basin and the identification of subbasins within the drainage basin that are exporting disproportionate amounts of nonpoint pollutants from their subbasins to the reservoirs. This information then was used to help the design of the monitoring network which is now incorporated into CWD's long-term water quality monitoring program.

Purpose

The purpose of this report is to characterize the health of the source water for the City of Cambridge for the 18 month period ending in December 2001. The report uses water-quality data from the 1998 USGS/CWD study as a baseline for comparison with data collected during the reporting period. Obtaining long-term water quality information is essential in guiding watershed management practices. By understanding where certain weater quality problems exist, City resources can be focused on these areas known to contribute contaminants to the reservoirs; in addition, watershed staff can evaluate the efficacy of their watershed management practices and re-prioritize their efforts if necessary.

The following sections describe the results of the water quality analyses conducted in each tributary and reservoir and provide a comparison to the USGS water quality study conducted in 1998. For a detailed discussion on the methods and process overview of the water quality monitoring program, refer to Appendix A.

Figure 1: Study Area

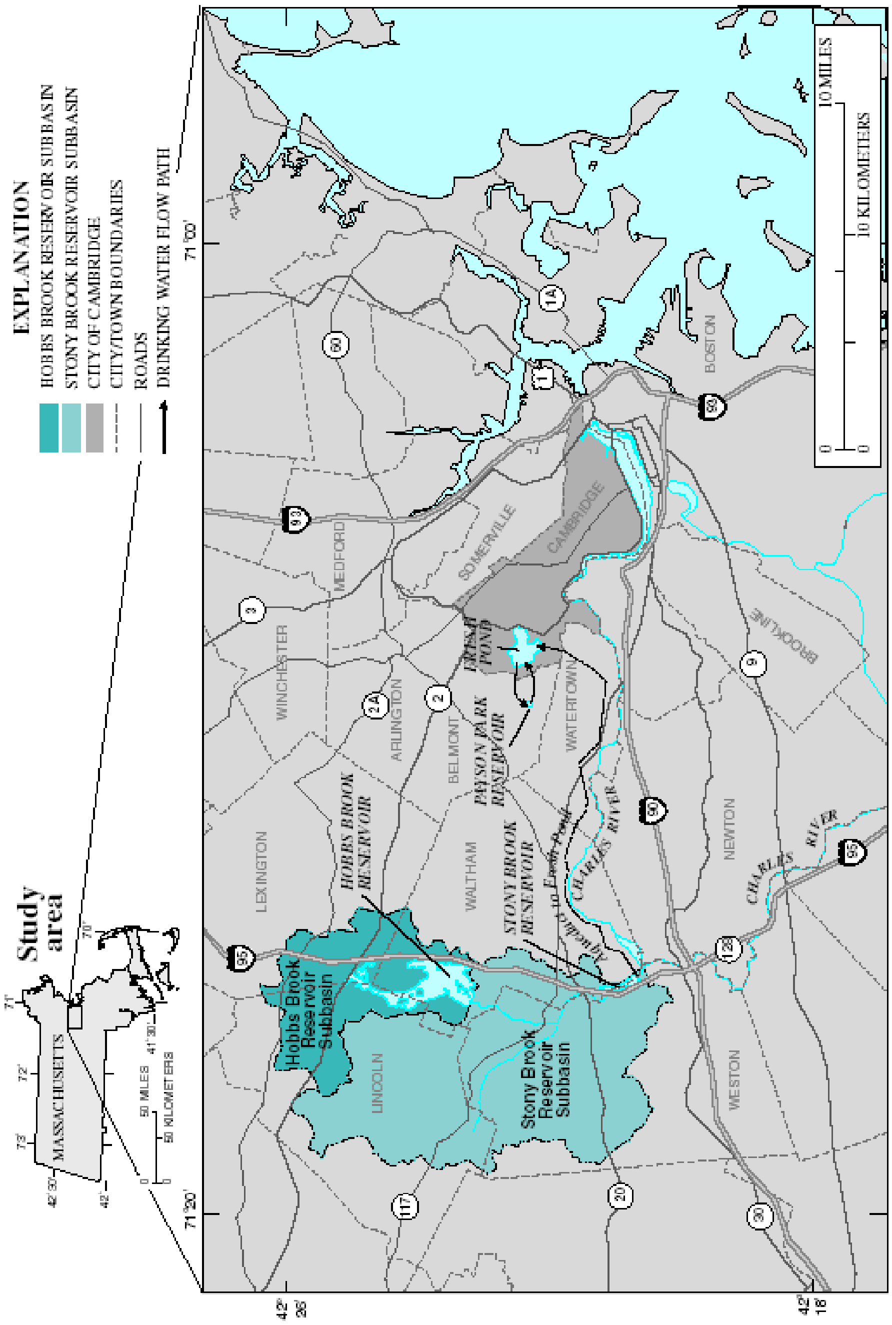
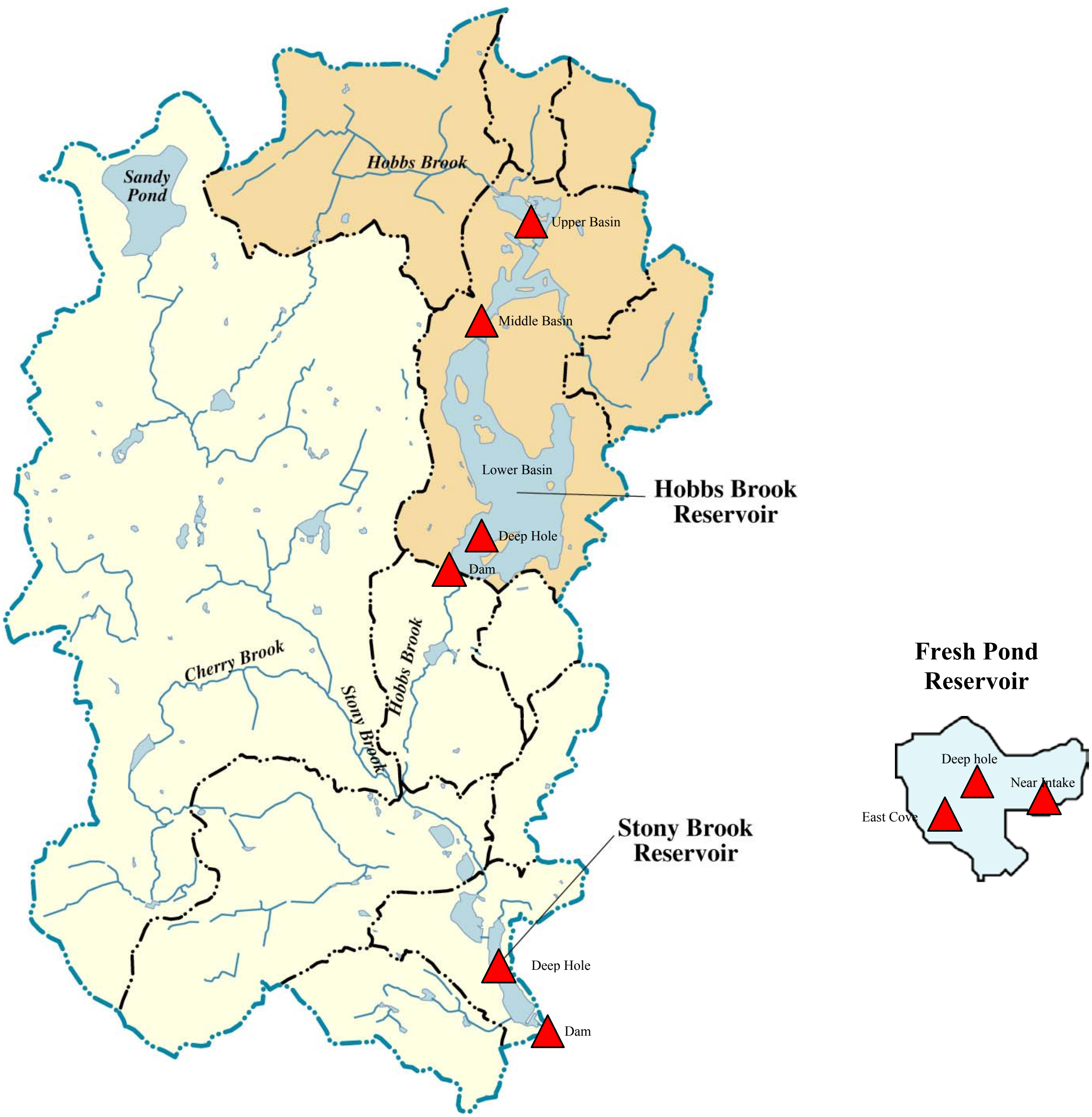


Figure 1. Location, extent, and components of the city of Cambridge drinking-water supply system, eastern Massachusetts.

Reservoir Water Quality

The following sections describe the physical, chemical, and biological changes observed in Hobbs Brook Reservoir, Stony Brook Reservoir, and Fresh Pond Reservoir over an 18 month period beginning in July of 2000 and ending in December 2001.

Figure 2: Reservoir Sampling Stations



Hobbs Brook Reservoir

Hobbs Brook Reservoir is divided into three separate basins; the upper and middle basins were sampled 13 times, while the lower basin was sampled 11 times during this study. Chlorophyll, nutrients, selected total metal samples and Secchi measurements were taken at the primary sampling station. Depth profiles of dissolved oxygen, pH, turbidity, temperature, and specific conductance, were made both at the primary sampling station, and at the secondary reservoir monitoring station where the gatehouse along Winter Street transfers water to Stony Brook Reservoir. Fecal coliform bacteria sampling was conducted during each visit to the secondary station.

A trophic state index (TSI – a numerical index indicating the degree of nutrient enrichment of a water body) for the lower basin was calculated from the chlorophyll-*a* concentrations and compared to the TSI values from the 1998 USGS/CWD study to determine general, long-term trends. Phytoplankton Chlorophyll-*a* concentrations, Secchi depth measurements, and overall calculated TSI for Hobbs Brook Reservoir is shown in the figure at the end of this report. These water quality parameters are directly affected by nutrients in the water column and therefore provide good indicators of overall water quality.

The TSI for Hobbs Brook Reservoir was lower than that of the 1998 USGS study (reference USGS study). The upper basin of the reservoir was shown to be in the mesotrophic range during this study. The middle basin was shown to be between the mesotrophic and the oligotrophic ranges, while the lower basin was primarily oligotrophic. A chart comparing the trophic state of the reservoirs and the Class B waters in Fresh Pond Reservation is shown at the end of the document.

The water column at the deep hole in Hobbs Brook reservoir began to show signs of thermal and chemical stratification in April and was fully stratified by July, as shown in the figures below. By October, the water column was mixed with relatively uniform temperature and dissolved oxygen concentrations.

Figure 3: Profile at the Deep Hole for Hobbs Brook Reservoir on April 23, 2001

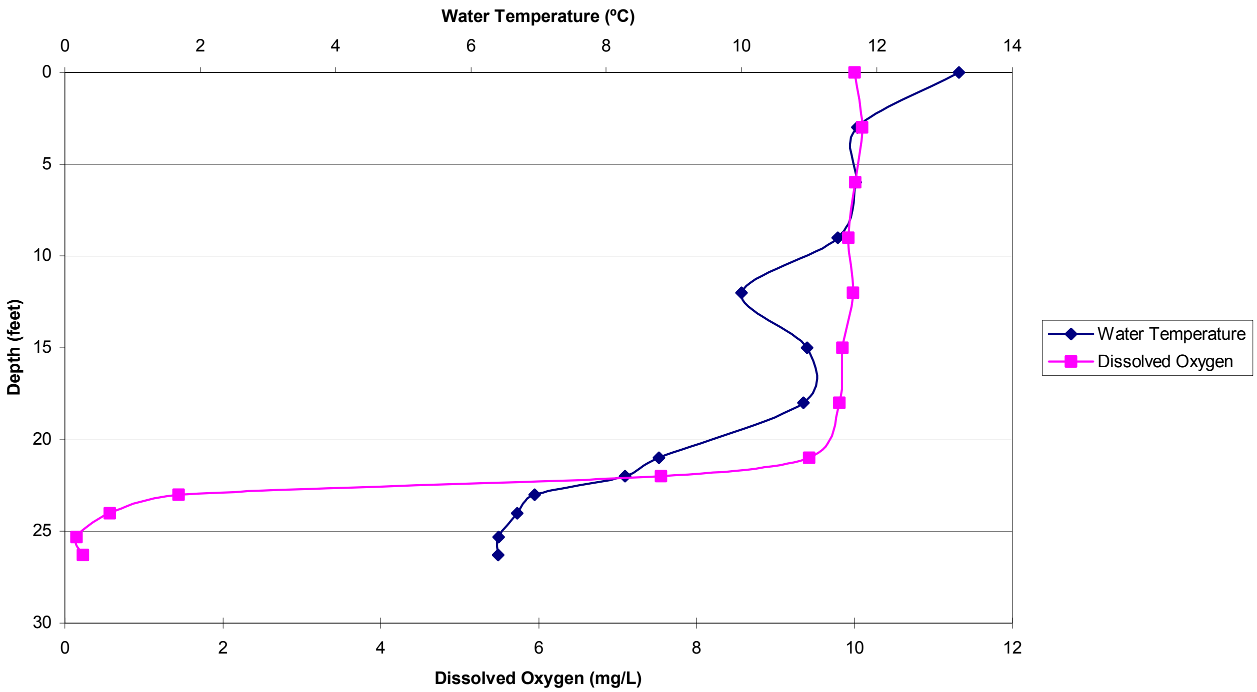


Figure 4: Profile at the Deep Hole in the Hobbs Brook Reservoir on July 19, 2001

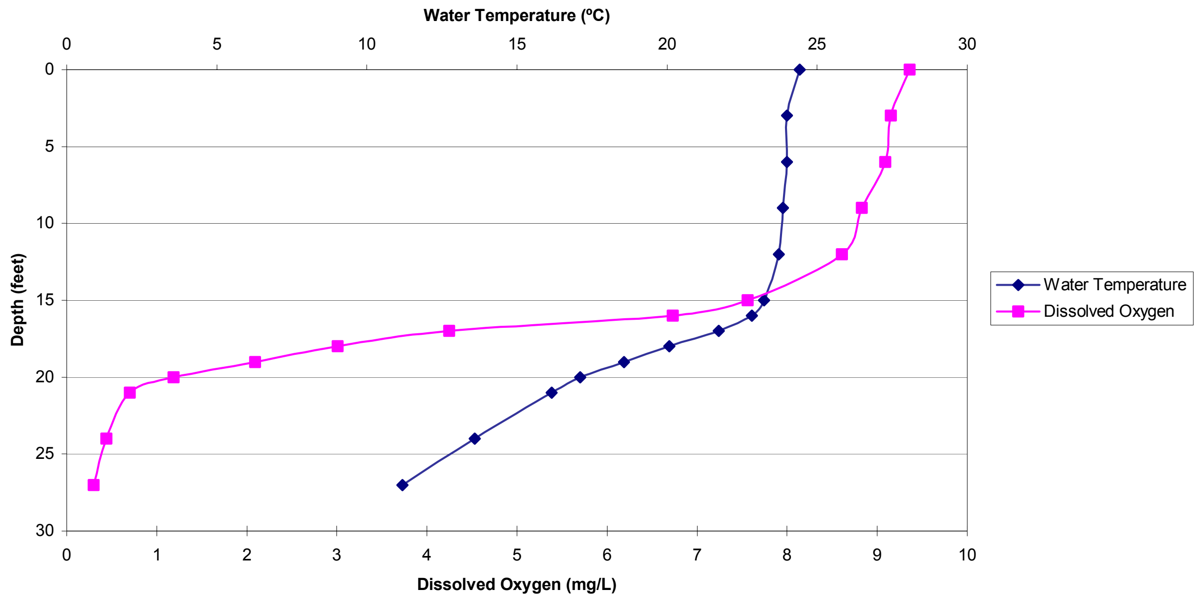
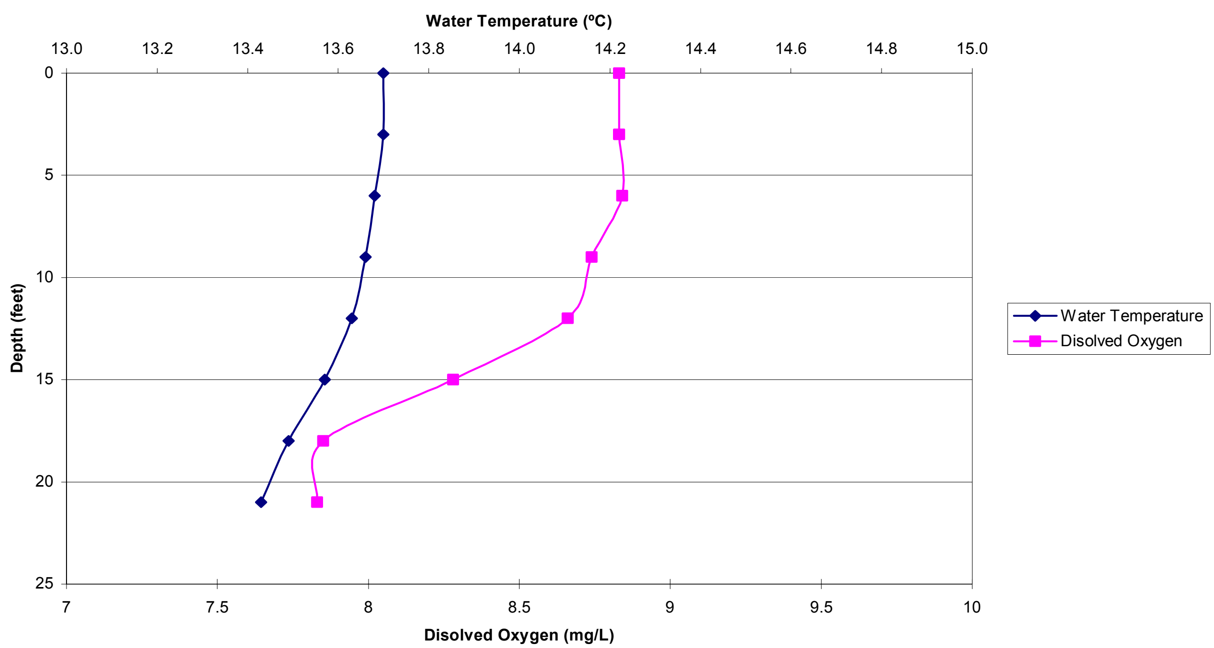


Figure 5: Profile at the Deep Hole in the Hobbs Brook Reservoir on October 28, 2001



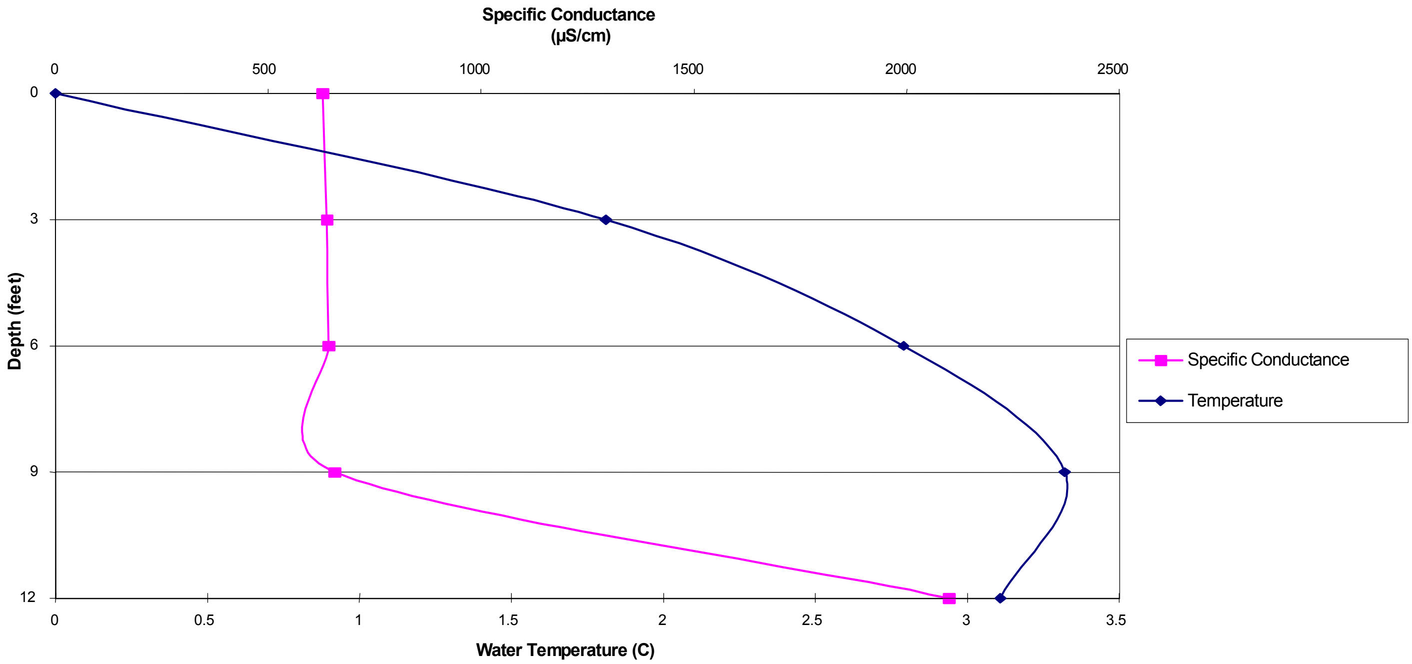
Winter 2000-2001 Conditions on Hobbs Brook Reservoir

Approximately 46 inches of snow was measured in the watershed area during the 2000 winter (NWS). Concentrations of sodium in the reservoirs and tributaries become elevated during harsh winters as a result of road salt applications on state roads, local roads, and commercial parking lots in the watershed. Overall sodium concentrations in Hoobs Brook Reservoir were greater than those in the 1998 study; this finding may be attributed to the nature and extent of precipitation that occurred during this winter. By December, 2001 ice covered the entirety of Hobbs Brook Reservoir. On January 18, 2001, transects across the lower basin were conducted where water-quality measurements were made through the ice at regular intervals. Water quality parameters measured were dissolved oxygen, pH, turbidity, temperature, and specific conductance. The transects revealed a distinct layer of high-conductance water near the bottom of the reservoir as shown in the figure below.

Figure 6 shows a layer of high-conductance water on January 18th near the bottom of the reservoir during a time of year when the water column is expected to be mixed. Concentrations of sodium were 90 and 320 mg/L in water samples colected at a depth of 3 and 15 feet on January 18th, 2001.

Dissolved sodium and and total nitrogen concentrations had increased from November and measurable amounts of nutrients were present. Higher specific conductance and sodium concentrations persisted throughout the remainder of the sampling period which continued through 2001.

Figure 6: Winter temperature and specific conductance depth profiles, January 18, 2001



Figures 7, 8, and 9 show chlorophyll concentrations were higher during the warmer months when biological productivity is the highest. Secchi depth measurements were made at the deep hole sampling station and are shown in the Figure 7; Secchi depth and chlorophyll concentrations are closely related as the water turbidity is caused largely by the presence of algae. Chlorophyll concentrations were highest in the upper basin of Hobbs Brook Reservoir, ranging from above 7 mg/m^3 in June to below 1 mg/m^3 in March; and were lowest in the lower basin of the Reservoir, ranging from just above the detection limit to just under 2.5 mg/m^3. These data are consistent with the 1998 USGS findings. Also, the charts appear to show a general trend of a late spring/early summer algal bloom, and an early fall algal bloom. This trend may be a result of different algal species blooming in two distinct time periods throughout the growing season. Algal speciation was beyond the scope of this study.

Figure 7: Concentrations of Chlorophyll in the Upper Hobbs Brook Reservoir, 2001

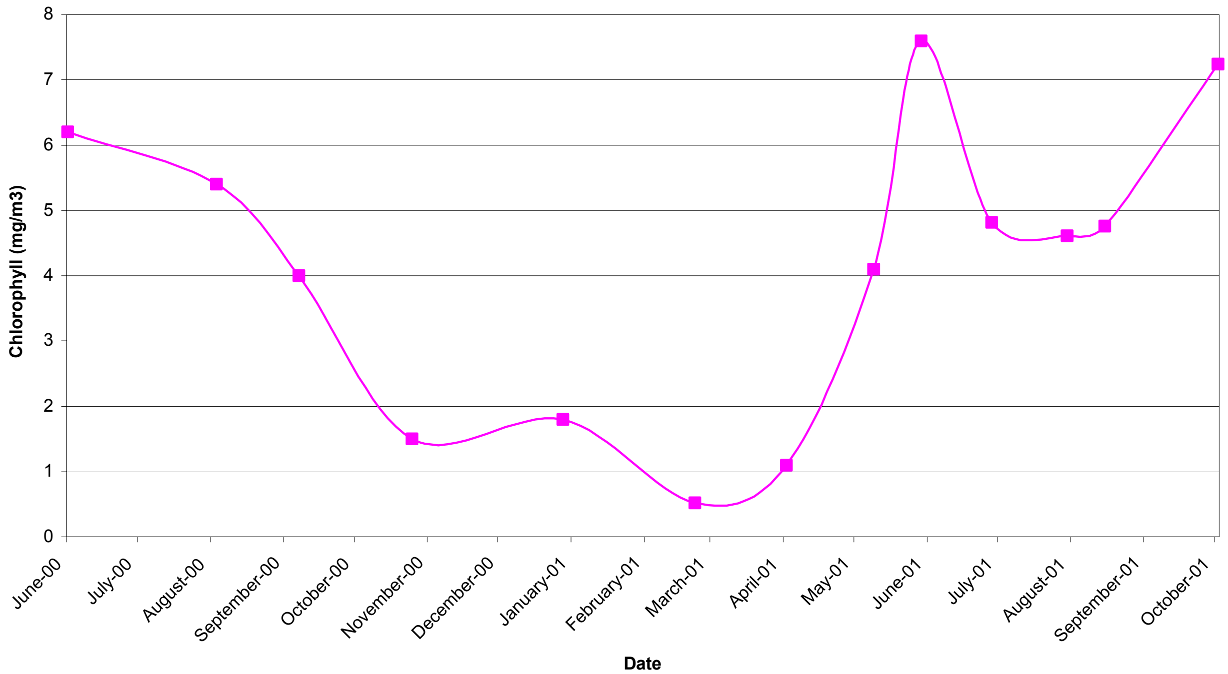


Figure 8: Concentrations of Chlorophyll in the Upper Hobbs Brook Reservoir, 2001

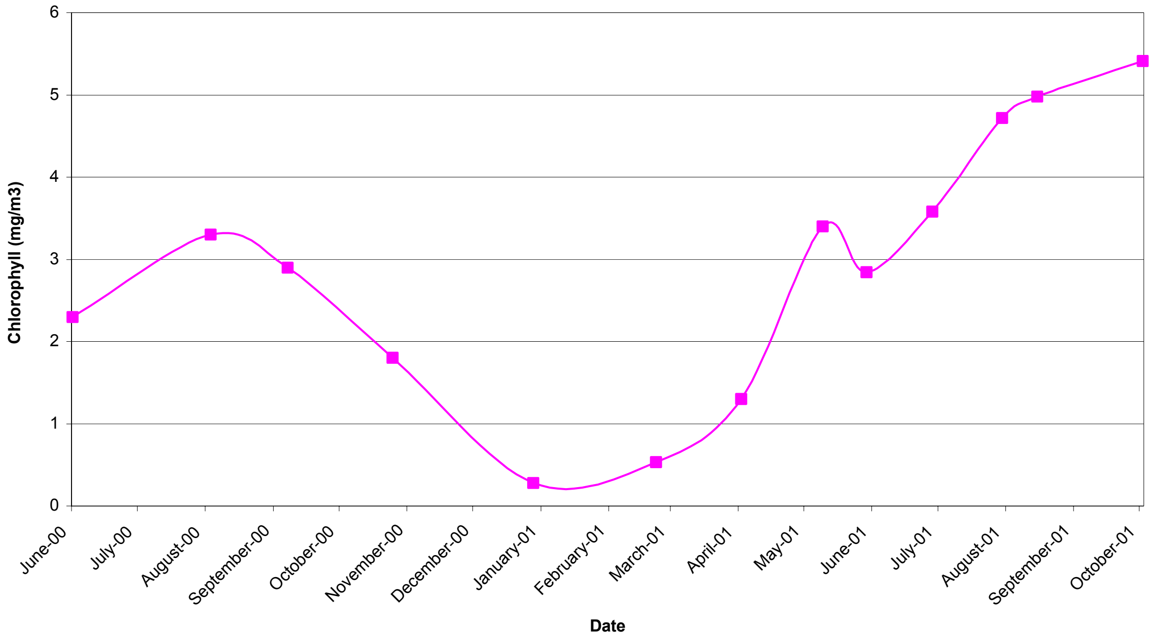
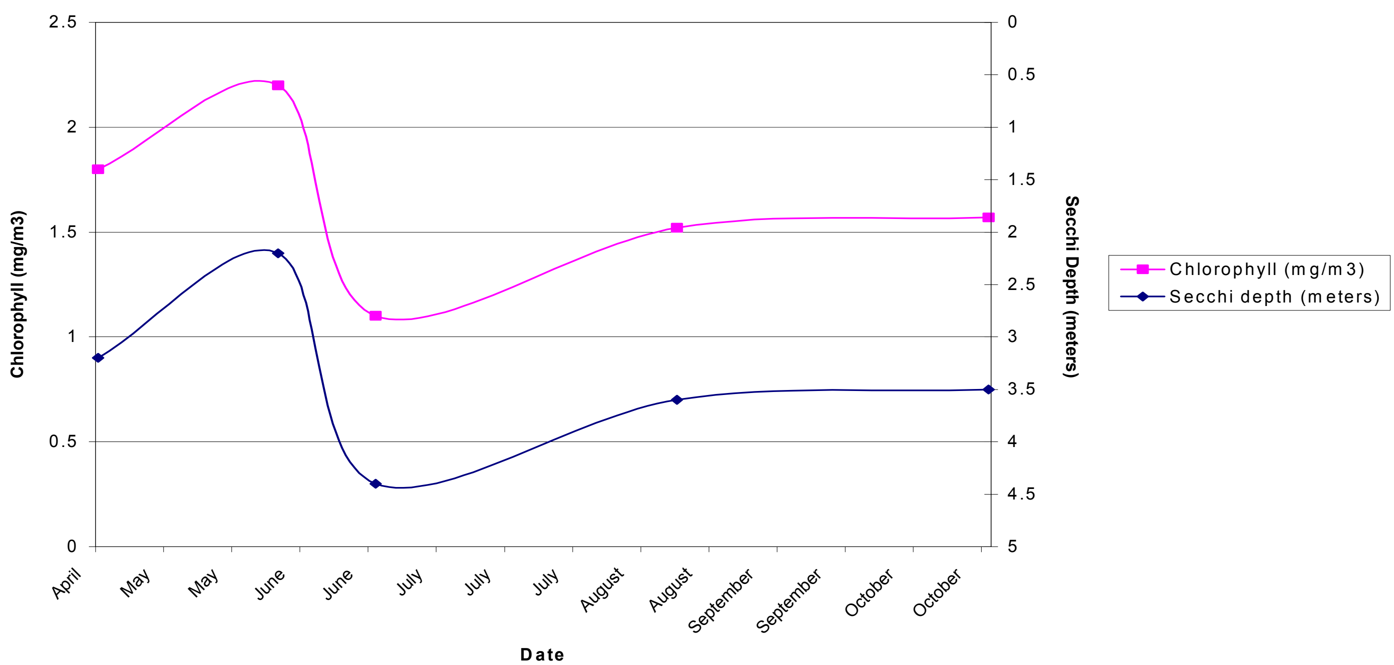


Figure 9: Concentrations of Chlorophyll in the Lower Hobbs Brook Reservoir, 2001



Stony Brook Reservoir

Water-column sampling at the deep hole in Stony Brook Reservoir began in April of 2001 and continued through December on nine separate field visits. Chlorophyll, nutrient, and selected total metal samples as well as Secchi measurements were collected at the deep hole. Depth profiles of dissolved oxygen, pH, turbidity, temperature, and specific conductance, were made both at the deep hole, and at the gatehouse that transfers water to Fresh Pond Reservoir via the Stony Brook Conduit. Water samples for the analysis of fecal coliform bacteria sampling were also collected during each visit to the gatehouse.

During most years, Stony Brook is artificially destratified with an aeration system however, during 2001 the aeration system was not operational until stratified conditions were observed due to major upgrades and renovations to the gatehouse. For this reason, stratified conditions were observed at the deep hole through October, 2001. In July, when stratified conditions peaked, the bottom 0.5 m was anoxic with a dissolved oxygen concentration of approximately 0.04 mg/L, and exhibited increases in pH and specific conductance relative to the upper mixed layer. Concentrations of most constituents analyzed were relatively uniform throughout the study with the greatest sodium concentration (320 mg/L) measured shortly after stratification had occurred at the end of May, 2001.

The water column at the deep hole in Stony Brook reservoir began to show signs of stratification in April and was fully stratified by July, as shown in the figures 10-12. By October, the water column was mixed with relatively uniform temperature and dissolved oxygen concentrations.

Figure 10: Profile at the Deep Hole in Stony Brook Reservoir on July 18th, 2001

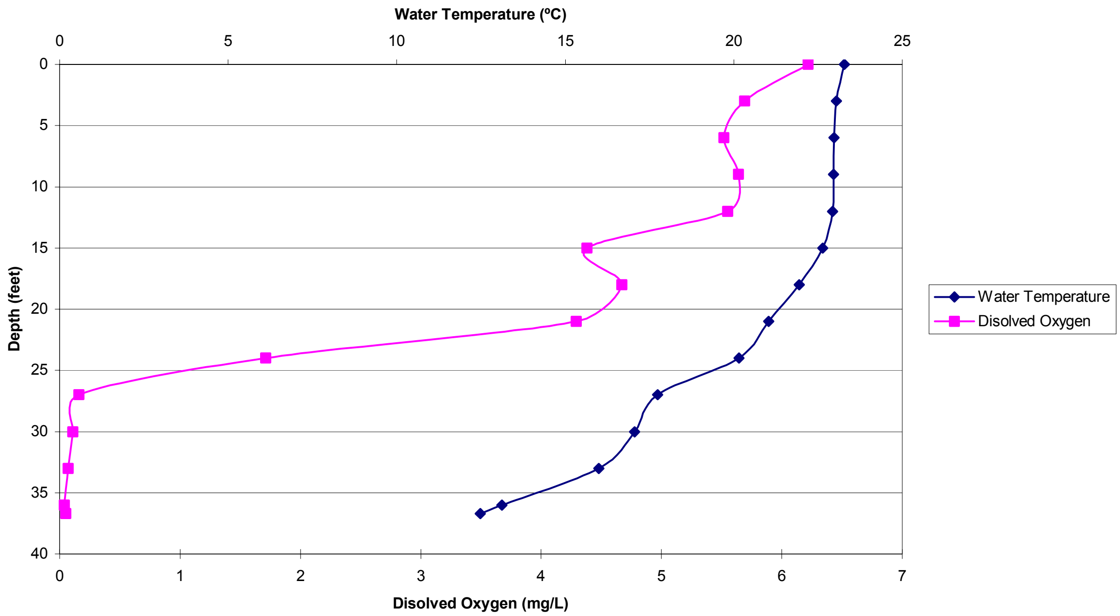
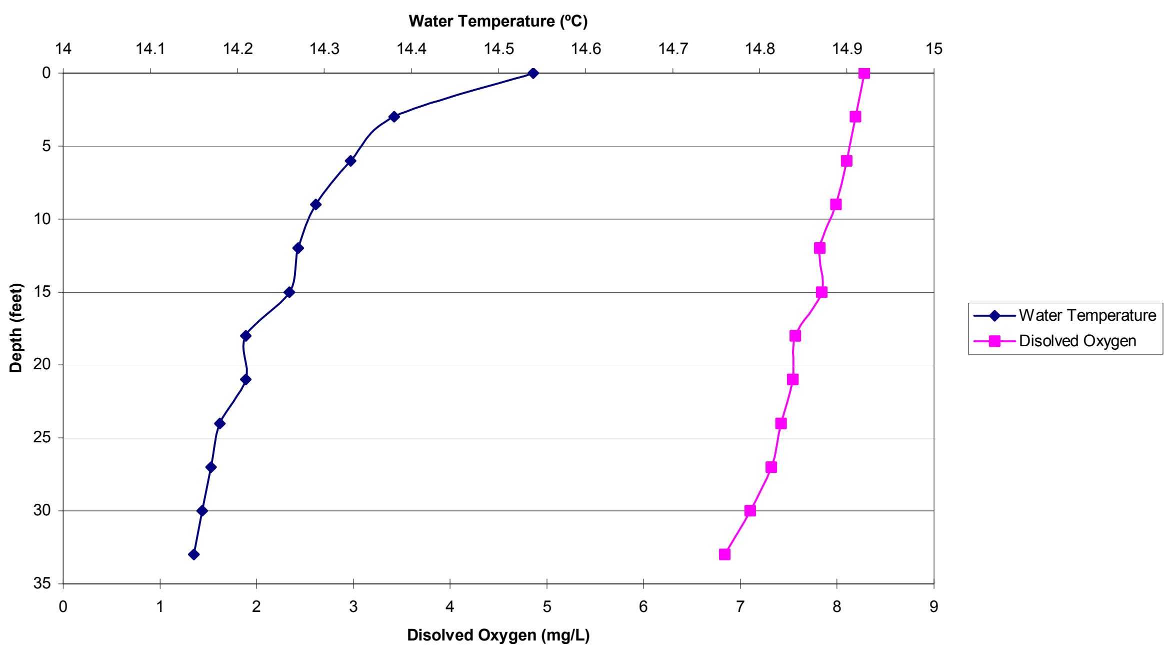
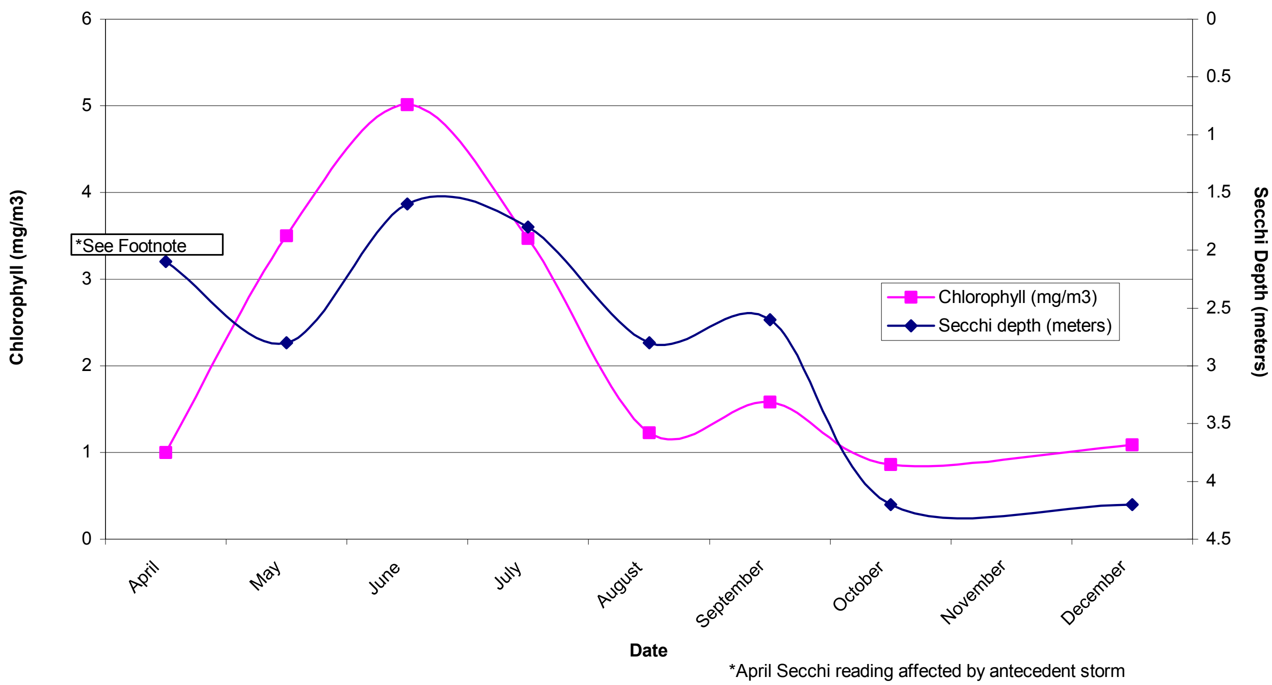


Figure 11: Profile at the Deep Hole in Stony Brook Reservoir on October 24th, 2001



Chlorophyll-*a* concentrations, and Secchi depth measurements for Stony Brook Reservoir are shown in the figure below. Algal productivity was the highest in June with another peak in early September. The overall TSI is displayed in the chart at the end of the water quality discussion in this report. These water quality parameters are directly affected by nutrients in the water column and therefore provide good indicators of overall water quality.

Figure 12: Stony Brook Reservoir at Deep Hole - Chlorophyll Concentrations and Secchi Depth Readings



In October, 2001, the the Water Filtration Facility in Cambridge was shut down for repairs and the gates at Hobbs Brook and Stony Brook Reservoirs were closed. This unusual scenario reduced flows through the reservoir that are typically high during periods of demand when the filtration plant is on-line. The lack of flushing of the reservoir may have had in impact on overall water quality and TSI values.

Fresh Pond Reservoir

At the beginning of the sampling period, Fresh Pond Reservoir did not receive water from the Hobbs and Stony Brook source area for the entire duration of the demolition of the old water treatment plant, and construction of the new treatment plant – a period of two years. Water-column sampling did not begin until August, 2000 although depth profiles were conducted in June and July. Fresh Pond is artificially destratified with an aeration system. Isothermal conditions were observed during the summer months to a depth of approximately 35 feet at which point dissolved oxygen levels remained low (0.10 mg/L in late August, 2000) to just above the bottom of the reservoir at 50 feet. Specific conductance values generally increased throughout the study period from 363 uS/cm in June, 2000 to 571 uS/cm in December, 2001. This can be attributed to influences from the up-stream source-water area during the winter of 2000-2001, and the fact that no water had been flowing into Fresh Pond from Stony Brook from 1998-to March of 2000 – yielding low initial sodium concentrations (35 mg/L, April 17th, 2001). With no surface in-flows and out-flows the water column in the reservoir was relatively clear, with unusually high Secchi depth readings.

Because Fresh Pond is artificially destratified with an aeration system, distict limnological layers within the Pond do not fully establish. In July, when stratified conditions peaked, only the bottom five feet were anoxic with a dissolved oxygen concentration of approximately 0.1 mg/L at the very bottom of the reservoir which during that measurement was at a depth of 50 feet (Figure 13). By early September, the water column was mixed and the temperature and dissolved oxygen was relatively uniform.

Figure 13: Thermal Profile at the Deep Hole in Fresh Pond Reservoir on July 17, 2001

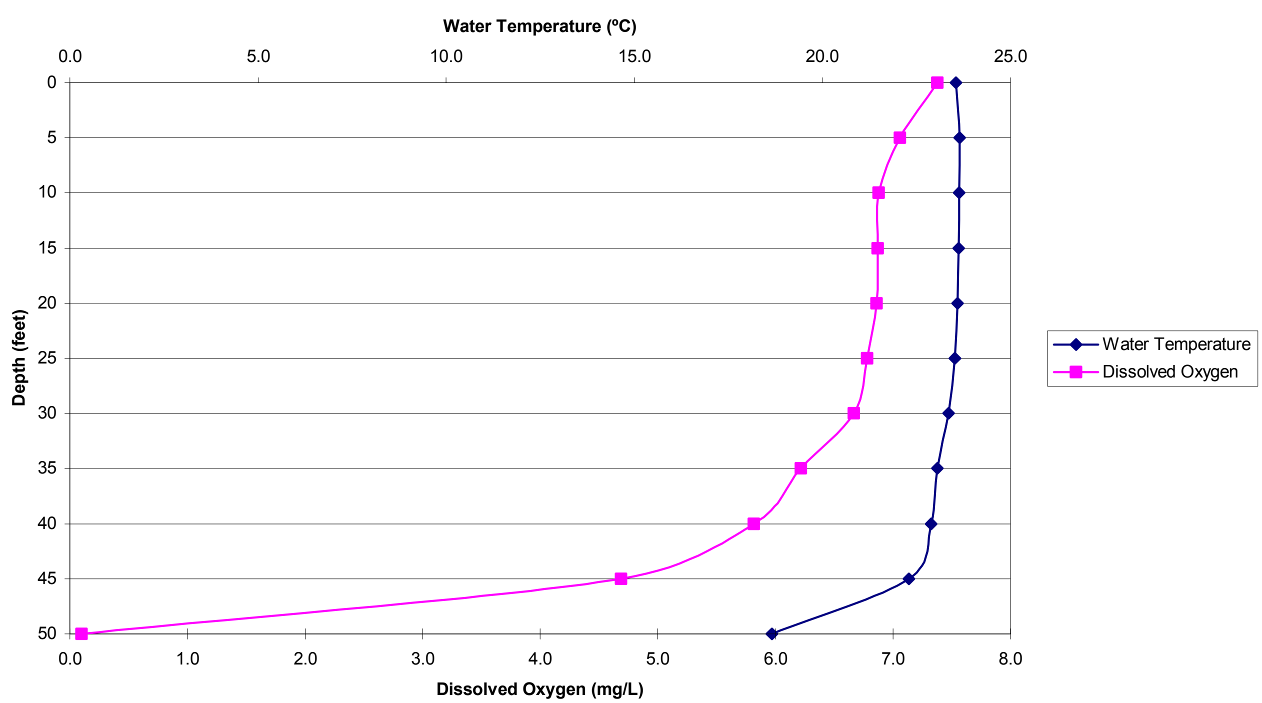
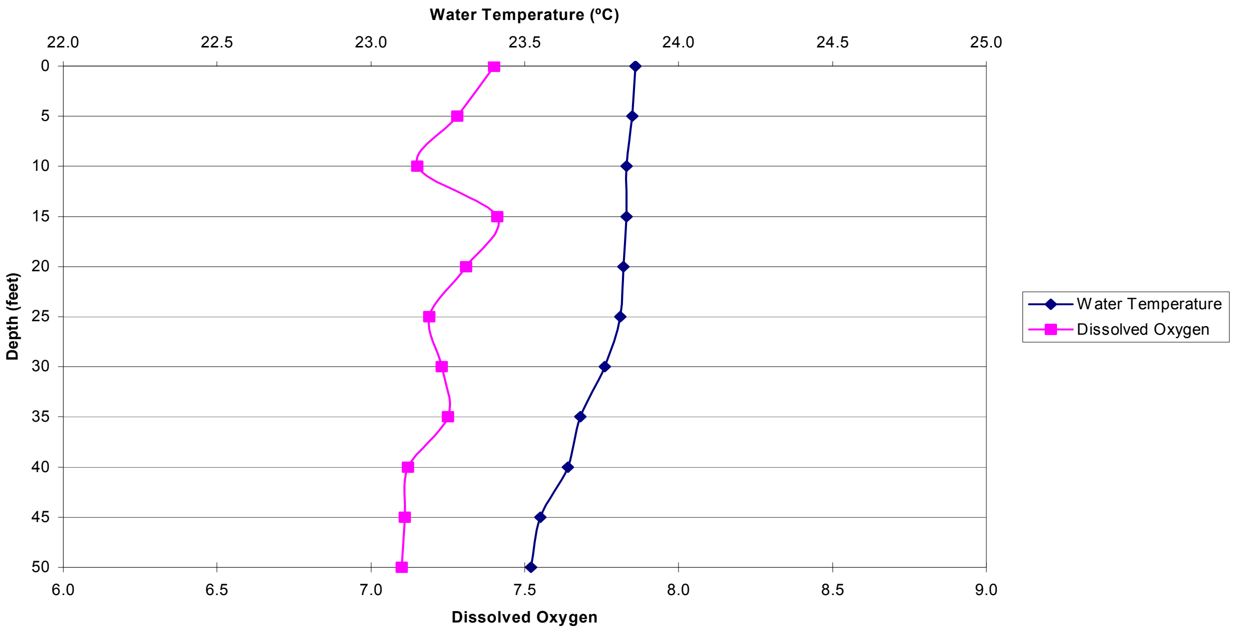


Figure 14: Thermal Profile at the Deep Hole in Fresh Pond Reservoir on September 6, 2001

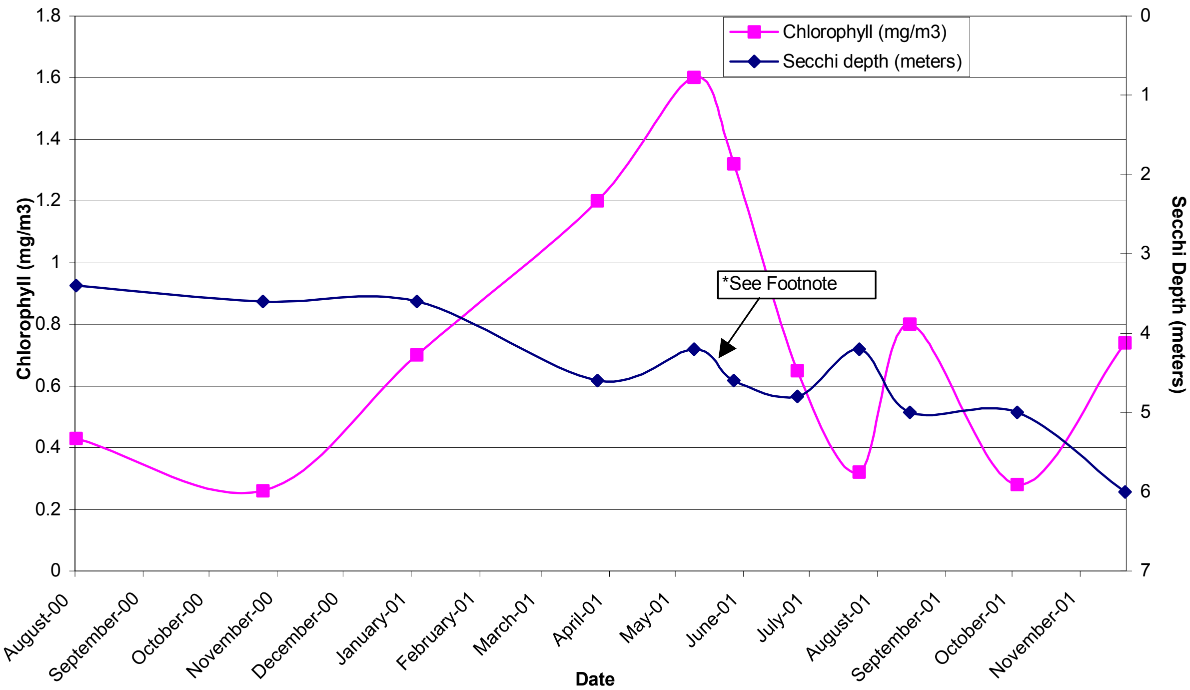


Generally, Fresh Pond had a lower chlorophyll concentration range and corresponding TSI value than that of the other two reservoirs, as shown in the TSI chart at the end of the water quality discussion of this report. This can be attributed to the fact that the reservoir also had relatively lower concentrations of nutrients than the other reservoirs in the system during the study period. The range of chlorophyll was much lower in Fresh Pond than that of the other two reservoirs (Figure 15).

Analytical results of samples collected in Fresh Pond yielded consistently low concentrations of nutrients and selected total metals, with manganese, sodium, chloride being the most abundant of the constituents sampled (8.2 mg/L on August 14th, 2001 was the highest manganese concentration value measured during the study period; sample taken from anoxic layer at bottom of reservoir).

The decrease in TSI values from Hobbs Brook Reservoir to Fresh Pond indicates an overall cascade effect in the Cambridge water supply system. Each reservoir acts as a settling basin which allows constituents affllilated with the sediments to settle to the bottom of each reservoir thereby improving the quality of the water as it moves through the source area. Thus by the time the water reaches Fresh Pond, the constituents that are measured in each water body have been transferred to the bed sediments in Stony Brook and in Fresh Pond and consequently are no longer in the water column. Sampling results over the year seem to support this phenomenon.

Figure 15: Fresh Pond Reservoir at Deep Hole – Chlorophyll Concentrations and Secchi Depth Readings for 2001



*August 2001 Secchi reading affected by rain the night before the sample was taken and heavy rain on 8/12/01.

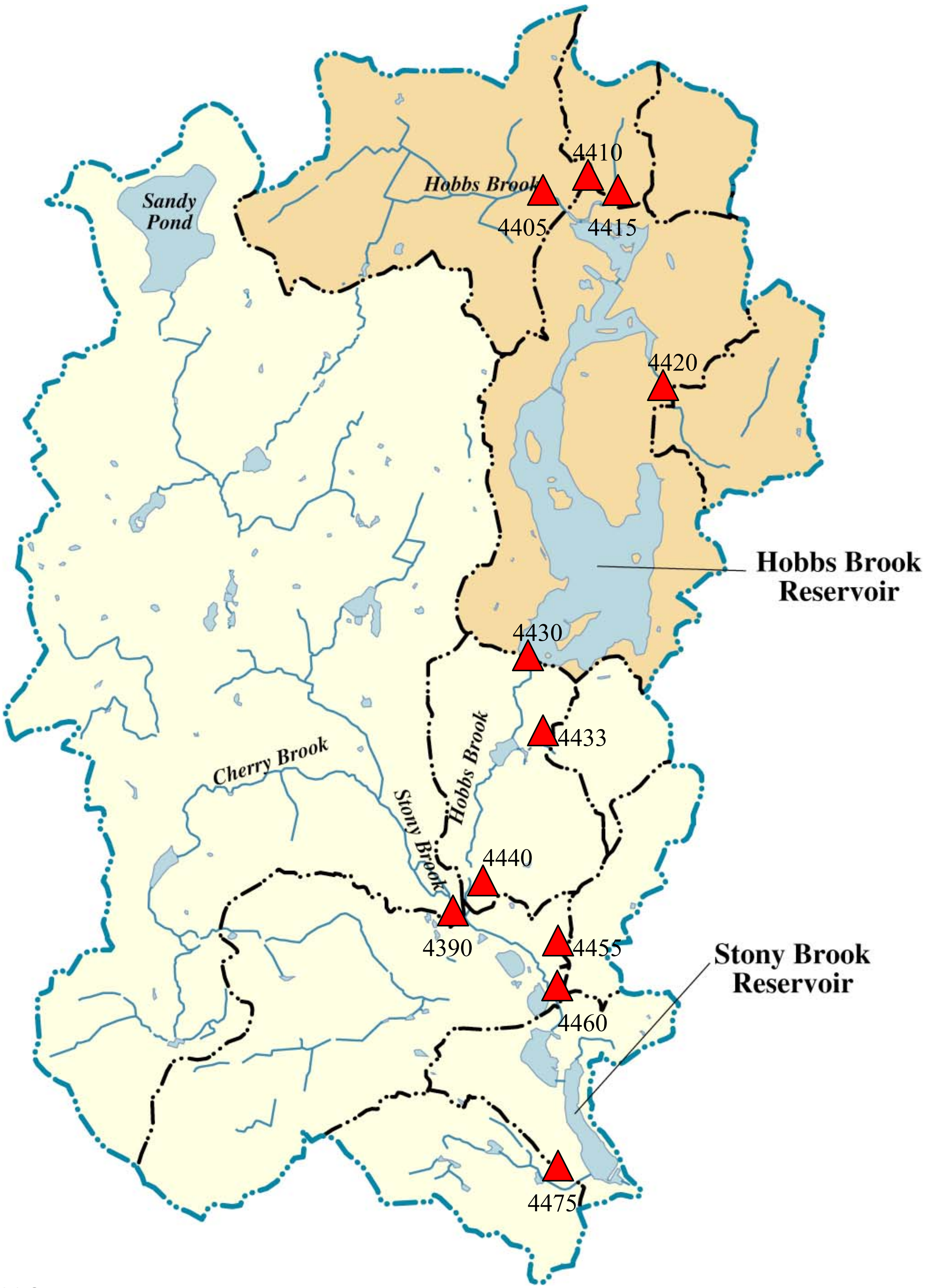
Tributary Water Quality

Sources of fecal coliform bacteria, dissolved sodium, dissolved chloride, nitrate nitrogen, total nitrogen, total phosphorus, dissolved iron, and dissolved manganese entering Hobbs Brook and Stony Brook Reservoirs were identified and constituent loads were quantified by calculating median instantaneous loads at key points in the drainage system over a 1-year period. These load estimates then were normalized to the areas of the subbasins resulting in instantaneous yields for each of the subbasins.

Discharge was measured at all except two tributary sampling stations with current meters according to Rantz and others, 1982. Stage was converted to discharge based on measured stage-discharge relations. At the two stations where discharge measurements were not made, the stage-discharge relation established from previous measurements was used to determine discharge. Three of the 11 primary tributary monitoring stations are equipped to continuously monitor stream stage, and specific conductance. The continuous-record stations are located upstream from Hobbs Brook Reservoir on an unnamed tributary, immediately downstream from Hobbs Brook Reservoir at the dam, and an unnamed tributary to Stony Brook Reservoir. Characteristics of each subbasin in terms of percent areal coverage of 21 land use/land cover categories, minimum, maximum, and mean, slope, and surficial geology are provided in the 2000 USGS report (Factors Affecting Reservoir and Stream Water Quality in the Cambridge, MA Drinking Water Source Area, USGS, Waldron, Marcus C., Bent, Gardner C, 1998).

All 11 primary tributary sampling sites (Figure 16) were sampled approximately every two months during the study period. Water samples for chemical analyses were collected at stream and reservoir sampling stations using clean-sampling protocols (Wilde and others, 1999) for all aspects of sample collection, preservation, and transport. Samples were collected either by the centroid dip technique or by combining volumes of water proportional to the amount of discharge at 10-12 equally spaced points along a stream cross section (Edwards and Glysson, 1999).

Figure 16: Primary Tributary Monitoring Stations



The following discussion highlights only the significant findings of tributary monitoring from north to south, throughout the watershed and provides a qualitative comparison of these findings with the 1998 USGS Study in order to observe any potential long-term trends in water quality. These findings relate to land use within each drainage area and implications for further study as well as watershed protection practices. Analyses results are displayed in the charts following this discussion.

Hobbs Brook at Mill Street (4405)

Hobbs brook is one of three tributaries that convey water to the upper basin of Hobbs Brook Reservoir. The subbasin defined by station 4405 (Hobbs Brook at Mill Street, near Lincoln, MA), at 5.59 km^2, is by far the largest of the three. The subbasin is comprised of a large proportion of wetland and forested cover relative to the other tributaries in the basin.

Relative to the other tributary sampling stations, 4405 exhibited lower estimated yields (mg/km^2) of manganese, total phosphorus, total nitrogen, and sodium. Overall manganese, sodium, and fecal coliform bacteria concentrations however, were slightly higher than those found in the 1998 USGS study, but concentrations of nitrate nitrogen were statistically the same. Dissolved oxygen concentrations were shown to have slightly decreased since 1998, but the median concentration still remains above the State standard of 6 mg/L for Class-A water bodies. Orthophosphate phorsphorus concentrations were relatively high compared to the other sampling stations (the highest value being 0.03 mg/L in November, 2001), but were not compared to USGS values since different detection limits were used in the analyses.

Sodium concentrations, as with all tributaries sampled during this study, increased since the 1998 study; this can possibly be attributed to the severity of the 2000-2001 winter and the application of de-icing compounds to the road surfaces. Compared to other stations, this station is not a major recipient of highway runoff, thus it yielded relatively low sodium concentrations, with the highest being 49 mg/L sampled in March, 2001.

Unnamed Tributary 1, near Lexington, MA (4410)

With an estimated drainage area of 0.91 km^2, this station contributed the highest instantaneous yields of manganese and total phosphorus of the three tributary sampling stations in the subbasin. However, orthophosphate phosphorus concentrations were similar to that of Hobbs Brook at Mill Street. Instantaneous yields of sodium and fecal coliform bacteria were also the highest of the three tributary sampling stations in the subbasin. The instantaneous yield of total nitrogen was slightly less that that of Hobbs Brook at Mill Street. Median concentrations of sodium and nitrate nitrogen were slightly higher than those found in the 1998 USGS study, while median fecal coliform concentration was slightly lower.

High sodium yields at this sampling station are consistent with upstream historical land uses of open salt storage piles associated with road de-icing operations. It is possible that over the years salt from these piles slowly migrated into the ground water and re-surfaces in the wetland that feeds this tributary. In addition, the percentage of floodplain alluvium in the subbasin is more than five times that of any other subbasin in the source area and this may account for the high median concentrations of phorsphorus and iron, since a high proportion of streamflow in the tributary enters as anoxic ground water rich in these constituents (USGS). Relatively high yeilds of fecal coliform bacteria may also be attributed to the wetland that contributes to this sampling station as wetlands typically provide habitat for an abundance of wildlife.

Unnamed Tributary 2, Lexington, MA (4415)

With a drainage area of 1.06 km^2, this station drains the second largest area in the subbasin and is fed by groundwater and direct discharges from highway and road surfaces. An automated gaging station that continuously records temperature, stage, and specific conductance is located at this sampling station, which by far exhibited the highest median specific conductance values and median sodium concentrations in the entire source water area; these values were also higher than those found in the 1998 USGS study (USGS). However, median instantaneous sodium yield was slightly lower than that of unnamed tributary 1 which indicates that streamflow in this tributary is lower by comparison since sodium concentrations at this station measured the highest in the entire source water area (630 mg/L in July, 2001, and 1600 mg/L during a storm in January, 2001). Median instantaneous yields of total nitrogen and total phosphorus were less than those of the other two tributaries in this subbasin as well as median concentrations of orthophosphate phosphorus. Median nitrate nitrogen concentration was lower than that found in the 1998 USGS study, although they are the third highest in the entire source water area and the highest in the subbasin, while median manganese conentrations compared closely to 1998 findings (USGS). Median fecal coliform concentrations are the lowest of the three tributaries in the subbasin yet show an increase since the USGS study.

Figure 17: Automated gaging station data for Unnamed Tributary 2 – Average Daily Stage and Specific Conductance for 2001

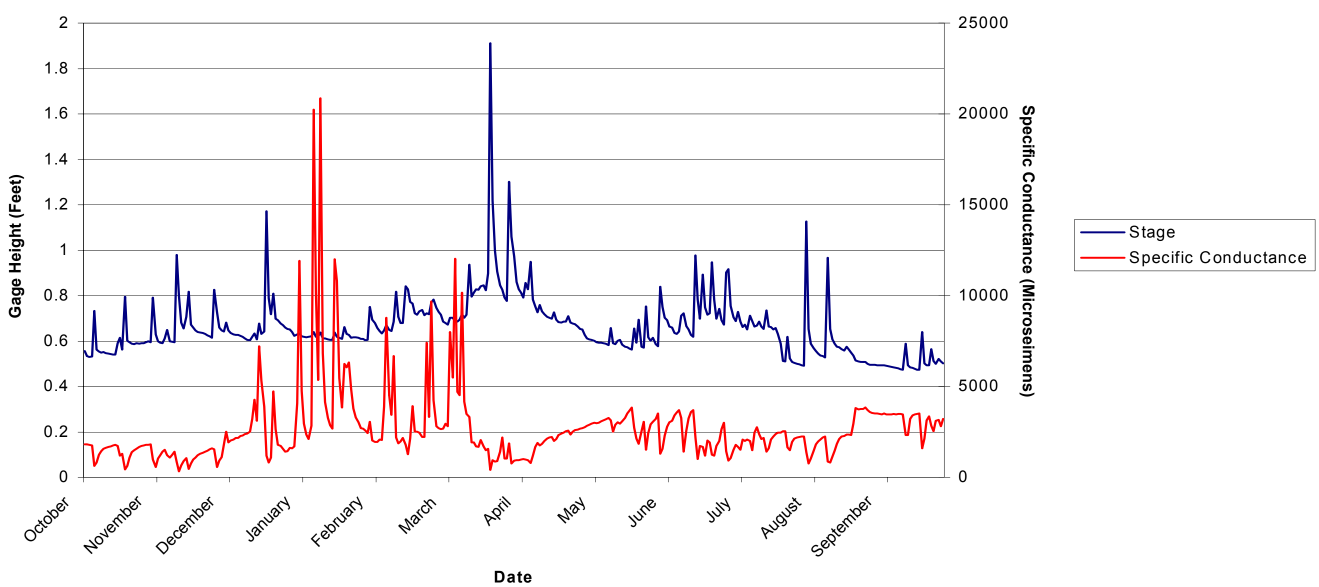


Figure 17 shows stage, which is an indicator of stream flow, and specific conductance which is an indicator of sodium and chloride concentrations in the water. These data were collected by an automated gaging station that is regularly maintained by the CWD. During months when the primary precipitation is rain, the graph depicts an inverse relationship between stage and specific conductance. This phenomenon is most likely the result of high-conductance groundwater caused by salt leaching into the surrounding aquifer from past highway practices, being diluted by rain storms, thus dropping the specific conductance values. Conversely, in the winter months when the precipitation is frozen, the relationship between specific conductance and stage is proportional, and large conductance increases are shown by spikes in the specific conductance record. This phenomenon can be explained by road salting practices during winter storm events that result in high sodium and chloride concentrations in highway runoff which enters the tributary from storm drains close to the monitoring station.

It is likely that much of the sodium contamination is related to highway runoff. More than 13 percent of the drainage area for this tributary is covered by roads, the highest coverage of any drainage area in the source watershed. The tributary's drainage area includes a major highway interchange connecting State routes 2A and 128 and a salt storage area managed by the MassHighway Department. State highways cover twice as much area in this subbasin as any other and are in close proximity to the sampling station, the tributary, and the reservoir. Inclusion of this station in a water-quality monitoring program is essential because of the serious potential for increased contributions of sodium and other contaminants to the water supply (USGS). This tributary will be incorporated into a detailed stormwater study to be carried out in cooperation with the USGS beginning in 2002.

Unnamed Tributary 3, Waltham, MA (4420)

Unnamed Tributary 3 enters the middle basin of Hobbs Brook Reservoir and receives runoff from State Routes 2, 128, a commercial parking lot, and also drains a wetland area east of Route 128. Nitrate concentrations in this tributary were shown to be less than those measured in the 1998 USGS study. In addition, the 1998 study found this station to have the largest maximum fecal coliform bacteria in the source water area. Although the median fecal coliform concentrations were comparable to that of the 1998 study, the maximum concentrations were less than all but one tributary monitored in this study. Median instantaneous sodium yield was very similar to that of station 4415, which may be expected given the similar environmental influences on both stations.

Hobbs Brook Below Dam (4430)

This station is directly downstream of the gatehouse that allows water to pass from Hobbs Brook Reservoir to Hobbs Brook continuing south to Stony Brook. Monitoring at this station in addition to taking open-water samples in the reservoir, provides futher information on the Reservoir water quality for which subsequent constituent loads and yields exiting the reservoir can be calculated and compared to the other subbasins in the system. For a portion of the study, the gates allowing water to flow through the gatehouse were closed since Cambridge was not using the supply, however, a nominal flow of water was continually released from the gatehouse even during this period.

Figure 18: Automated gaging station data for Hobbs Brook Below Dam - Average Daily Flow and Specific Conductance for 2001

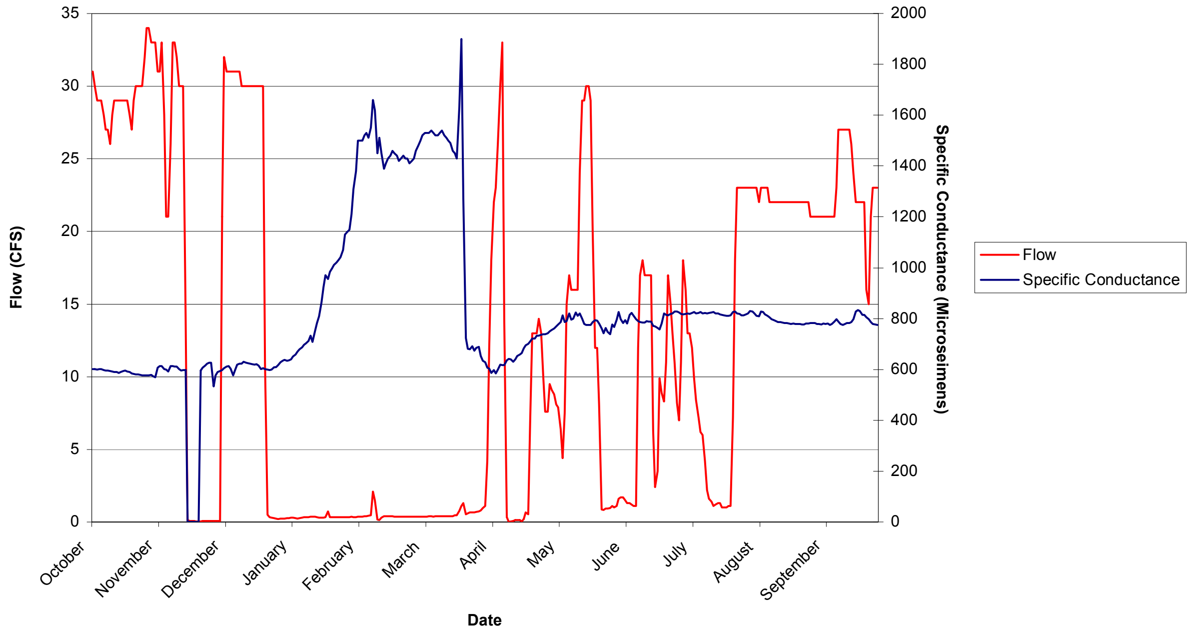


Figure 18 reflects both flow of water exiting the reservoir and passing this sampling station downstream, and the specific conductance of the water throughout the year. The flow fluctuates as floodwater passed over the spillway and as the gates were either opened or shut. Hobbs Brook Reservoir is typically shut for the duration of the winter when enough precipitation is recharging Stony Brook Reservoir. An estimated 2.912 billion gallons flowed past this station during the year, more than 100% of the reservoir's estimated total volume (2.497 billion gallons). Late winter floods in March 2001 may have been a major contributor of this volume of water. Two distinct patterns are evident in this chart: the first is the winter shutting of the gates; and second is the winter rise in specific conductance. This conductance spike is most likely attributed to salt laden highway runoff that occurs during winter storms. Monitoring of other tributary sites supports this phenomenon.

Because of dilution throughout the reservoir, concentrations of most constituents were relatively low compared to other subbasins throughout the system. Median instantaneous yields of phosphorus and nitrogen were relatively low compared to the other subbasins; however, median nitrogen concentrations were higher than those found in the 1998 USGS study. Median sodium concentrations were higher than those found in the 1998 USGS study, and similar to the findings of that study, median sodium concentrations in the Hobbs Brook subbasin as a whole were higher than those in the Stony Brook subbasin. This finding can be attributed to the difference in land cover of State and locally maintained roadways between the two watersheds. In addition, the 2000-2001 winter was particularly severe and most likely resulted in increased salt application on the roadways. This station showed the greatest variability of manganese concentration and the highest manganese concentration was measured at this site (0.83 mg/L in March, 2001).

Hobbs Brook, Unnamed Tributary 1, near Kendal Green (4433)

This station is on a small tributary that enters Hobbs Brook approximately 1km downstream from the dam (Figure 17). The subbasin drains a small forested wetland and has the greatest densities of commercial and industrial land use of any subbasin in the source area (USGS). The median concentration of orthophosphate phosphorus (0.26 mg/L in September, 2000) and fecal coliform bacteria were the highest in the source area. Overall fecal coliform concentrations were higher than those found in the 1998 USGS study. The median sodium concentration and associated instantaneous sodium yield was the second highest in the source area, and showed an increase compared to the 1998 USGS study. Large mats of algae were observed during field visits to this station in the growing season which may be an indicator of nutrient loading in the tributary. The presence of thick algal mats observed during several visits in the growing season were likely the cause of elevated dissolved oxygen levels measured during the growing season which generally is a desireable condition, however algal blooms cause only temporary increase in dissolved oxygen levels which subsequently drop during the winter months as the decaying algae consume the oxygen.

There appears to be a continued potential for significant contaminant transport from this subbasin. However, the wetland in the subbasin and a small ponded area downstream from the station probably reduce the potential for serious contamination of Hobbs Brook. Continued monitoring at this station is proposed as well as its incorporation into a detailed storm water study which will occur in 2003.

Hobbs Brook at Kendal Green (4440)

Station 4440 is important because it integrates water and constituent loads from the entire Hobbs Brook subbasin. The station is located just upstream from the confluence of Hobbs Brook and Stony Brook (Figure 17) and affords useful comparisons with monitoring data collected at the adjacent Stony Brook station. This station is a good overall indicator of water quality in Hobbs Brook Reservoir and although the City of Cambridge was not using this reservoir for some time during this study, a nominal flow of water was continually released from the reservoir into Hobbs Brook. Incidentally, the water quality at this station was relatively good with very low concentrations of nutrients. Fecal coliform and manganese yields were high compared to most of the other stations however this may be attributed to generally higher stream flow levels as water at this station is controlled by operation of the upstream reservoir. Median fecal coliform concentrations were less than that of the 1998 USGS study however, median sodium, manganese and nitrate concentrations were higher than that of the USGS study.

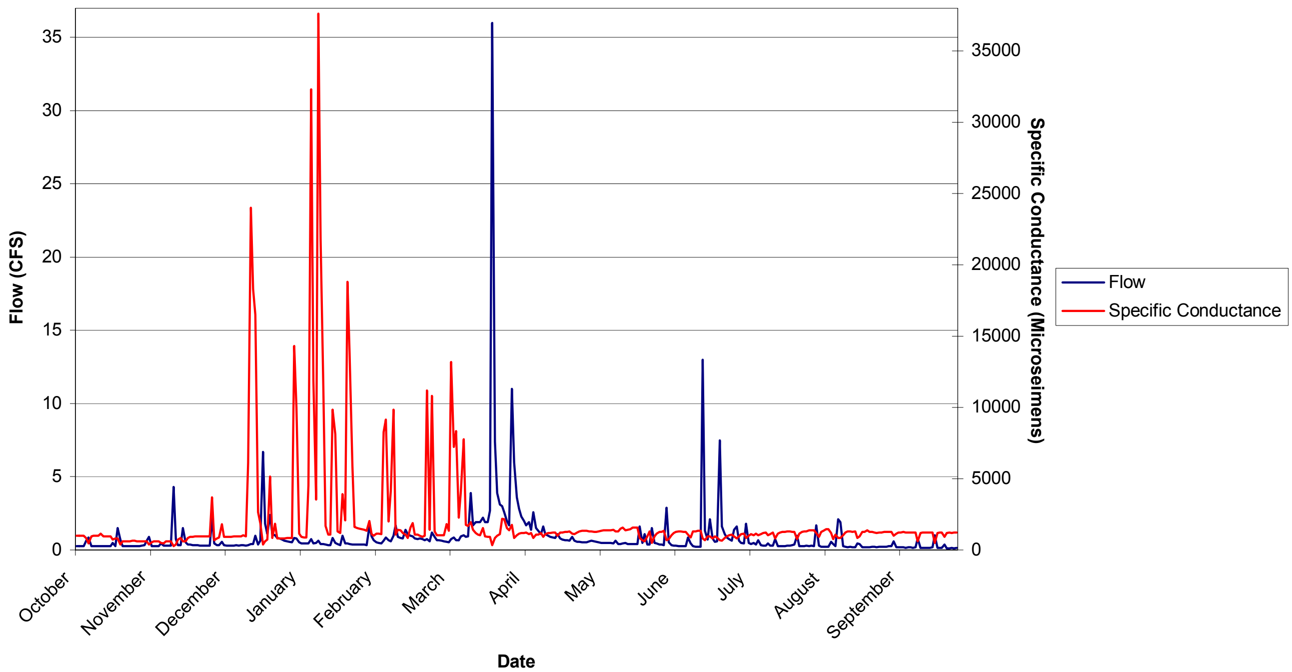
Stony Brook at Kendal Green (4390)

This station is located on Stony Brook just upstream from its confluence with Hobbs Brook (Figure 17). As such, water-quality data from the station integrates and represents conditions in a subbasin that comprises more than half of the total source-water area. Land use and land cover however, are appreciably different in the two integrator subbasins. The Stony Brook subbasin contains significantly less commercial and industrial land and a larger amount of low-density residential land use. Both subbasins produced relatively large estimated yields for fecal coliform bacteria although bacterial concentrations were not the highest measured throughout the network. Concentrations of phorphorus were relatively low in Stony Brook however, nitrate concentrations were some of the highest throughout the sampling network (Figure 17). Despite relatively high nitrate concentrations, the weighted instantaneous yield for this station was not the highest of the source-water area. Nitrate levels are most likely attributed to natural organic matter associated with wetlands and forest that are located upstream in the Stony Brook subbasin.

Stony Brook Unnamed Tribuary 1 – WA-17 (4455)

This station discharges through a small wetland to Stony Brook approximately 0.7km upstream from Stony Brook Reservoir. The subbasin contains significant amounts of State and locally-maintained roads, and commercial and industrial land use. Much of the lower part of the subbasin is paved and this part of the stream is routed through culverts that directly drain State Route 128 and the interchange connecting Routes 128 and 20.

Figure 19: Automated gaging station data for Stony Brook, Unnamed Tributary 1 (WA-17) - Average Daily Flow and Specific Conductance for 2001



As described earlier for Lexington Brook, data for Stony Brook Unnamed Tributary 1 shows dramatic changes in specific conductance which relate directly to sodium and chloride concentrations in the water. These data are collected by an automated gaging station that is regularly maintained by the USGS. During months when the primary precipitation is rain, the graph depicts an inverse relationship between stage and specific conductance. This phenomenon is most likely the result of high-conductance groundwater caused by salt leaching into the surrounding aquifer from past highway de-icing practices, being diluted by rain storms, thus dropping the specific conductance values. Conversely, in the winter months when the precipitation is frozen, the relationship between specific conductance and stage is proportional, and large conductance increases are shown by spikes (Figure 19). This phenomenon can be explained by road salting practices during winter storm events that result in high sodium and chloride concentrations in urban runoff which enters the tributary from storm drains close to the monitoring station.

During the reporting period, this station contributed the highest instantaneous yields of sodium, manganese, and nitrate of any other station in the sampling network (Figs – 20-25). Median sodium concentrations were higher than those found in the USGS study, but median nitrate concentrations were less and median manganese concentrations were the same. At this station median fecal coliform bacteria concentrations exceeded the State standard for Class A waters on every sample taken and were generally higher than those found in the 1998 USGS study. Because of its proximity to Stony Brook Reservoir, constituent loads from this subbasin may have affected the quality and trophic state of the reservoir. Furthermore, the large amount of impermeable surface area in the subbasin near the monitoring station resulted in very rapid increases in discharge in response to precipitation and stormwater runoff. Data collection during this 2001 study supports the 1998 USGS report recommendations to design and install an automated sampling system at this station, and to maintain a continuous record of discharge and specific conductance. This station will be incorporated into a detailed stormwater study currently being implemented by the USGS in cooperation with CWD.

Stony Brook at Route 20 (4460)

This station integrates the main part of the source area upstream from Stony Brook Reservoir. Most of the water that enters the Reservoir passes this station (Fig 16), thus this is one of the largest tributaries in the sampling network, contributing the highest volume of water to the reservoir. Median instantaneous yields of phosphorus and fecal coliform bacteria were the highest in the sampling network. However, most other constituents measured were moderate relative to other subbasins throughout the study network. Continuous monitoring of this station will provide important information on the quality and quantity of water entering Stony Brook Reservoir. This station will be incorporated into a detailed stormwater study by the USGS and CWD; an automated sampler and a multi-parameter water quality probe will be installed. Continuous water quality data will be available on the internet.

Stony Brook at Summer Street near Weston (4475)

This station is located on a small tributary that discharges directly into Stony Brook Reservoir near the intake. Land use in the subbasin differs from the others in that there is relatively little forest, no State-maintained roads, and no commercial or industrial development. The predominant land use in the subbasin is low density residential. Median concentrations of manganese and sodium were low relative to the other sampling stations, but showed an increase from the USGS 1998 study results. Instantaneous nitrate yields were the second highest in the source water area, and median nitrate concentrations showed an increase from those reported in the USGS study. Although median fecal concentrations were higher than those found in the USGS study, median instantaneous yields of fecal coliform bacteria were low relative to the other stations. This parameter is of concern since the residential areas in this subbasin are predominantly on septic systems. It is possible that the nitrate levels detected at this station are associated with septic systems in the subbasin but are most likely attributed to fertilizers on residential lawns and the presence of a golf course up stream. Because the land use in this subbasin differs from that of the others, and appears to be a source of nutrients to Stony Brook Reservoir, this station will be included in the USGS/CWD stormwater study in 2002-2003.

Figure 20: Fecal Coliform Concentrations for Tributary Monitoring Stations 2001

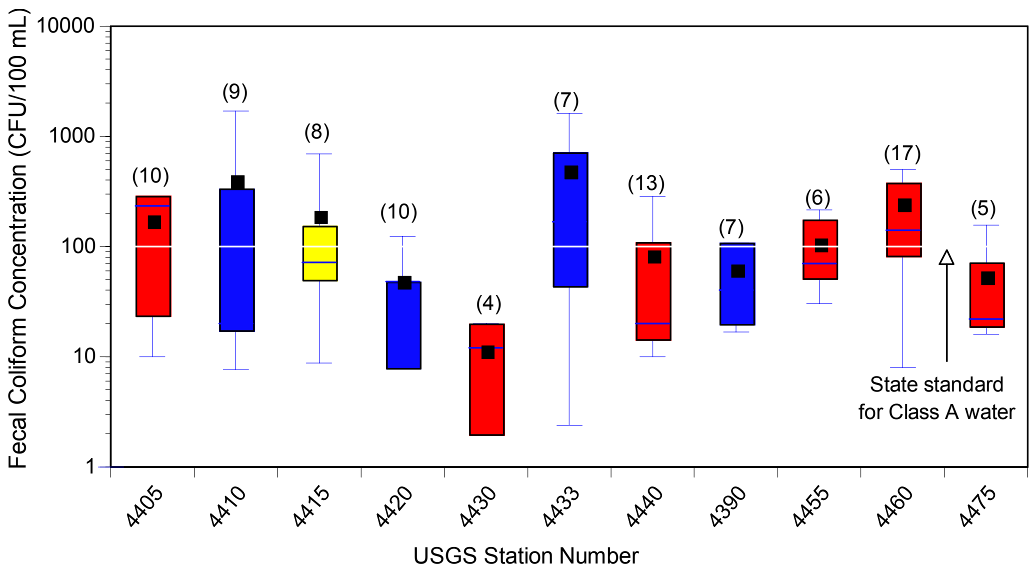
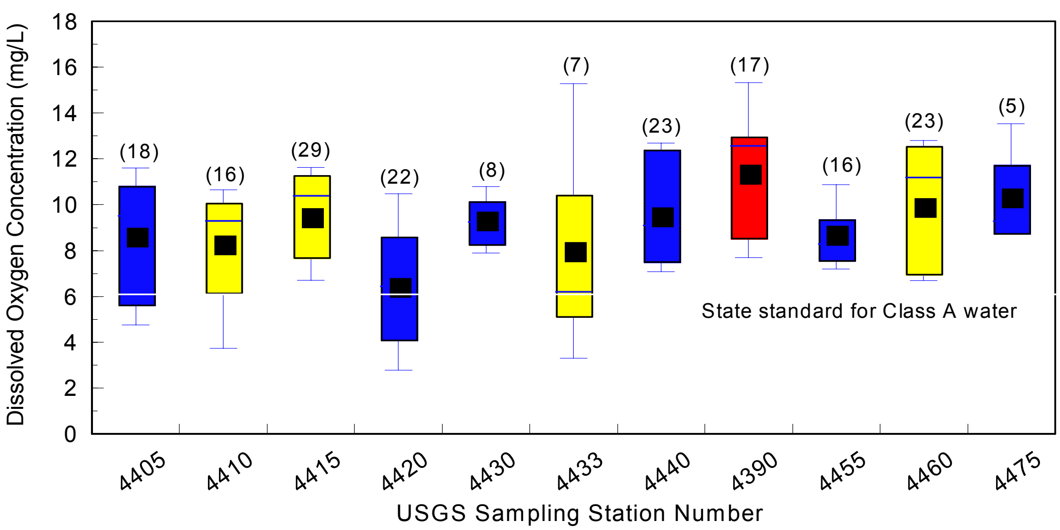


Figure 21: Dissolved Oxygen Concentrations for Tributary Monitoring Stations, 2001



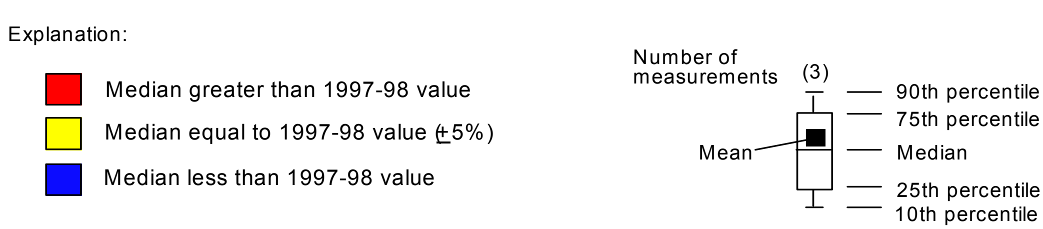


Figure 21: Manganese Concentrations for Tributary Monitoring Stations 2001

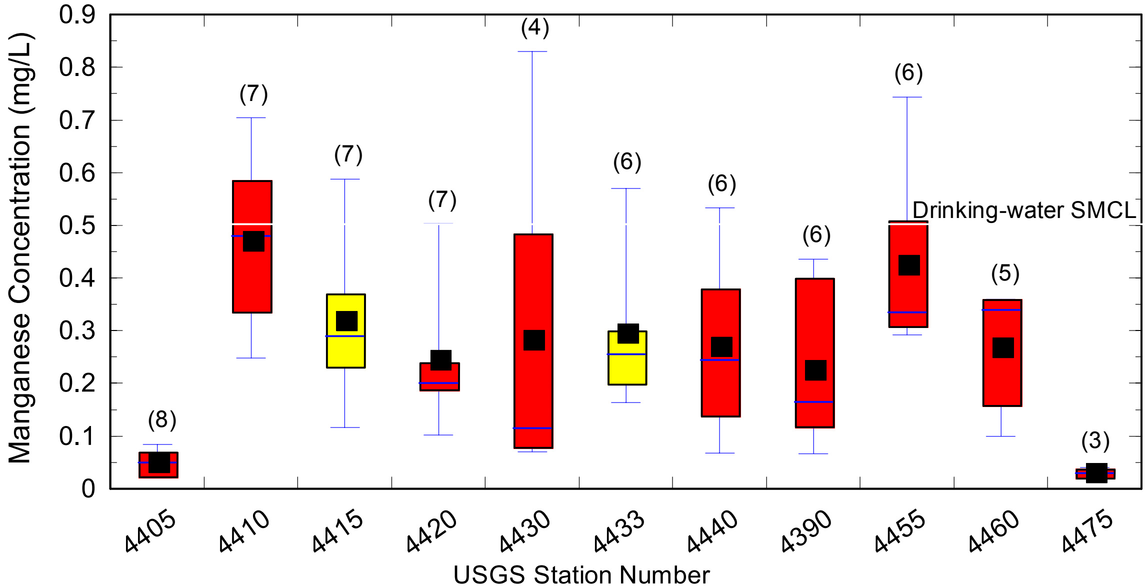


Figure 22: Nitrate Concentrations for Tributary Monitoring Stations 2001

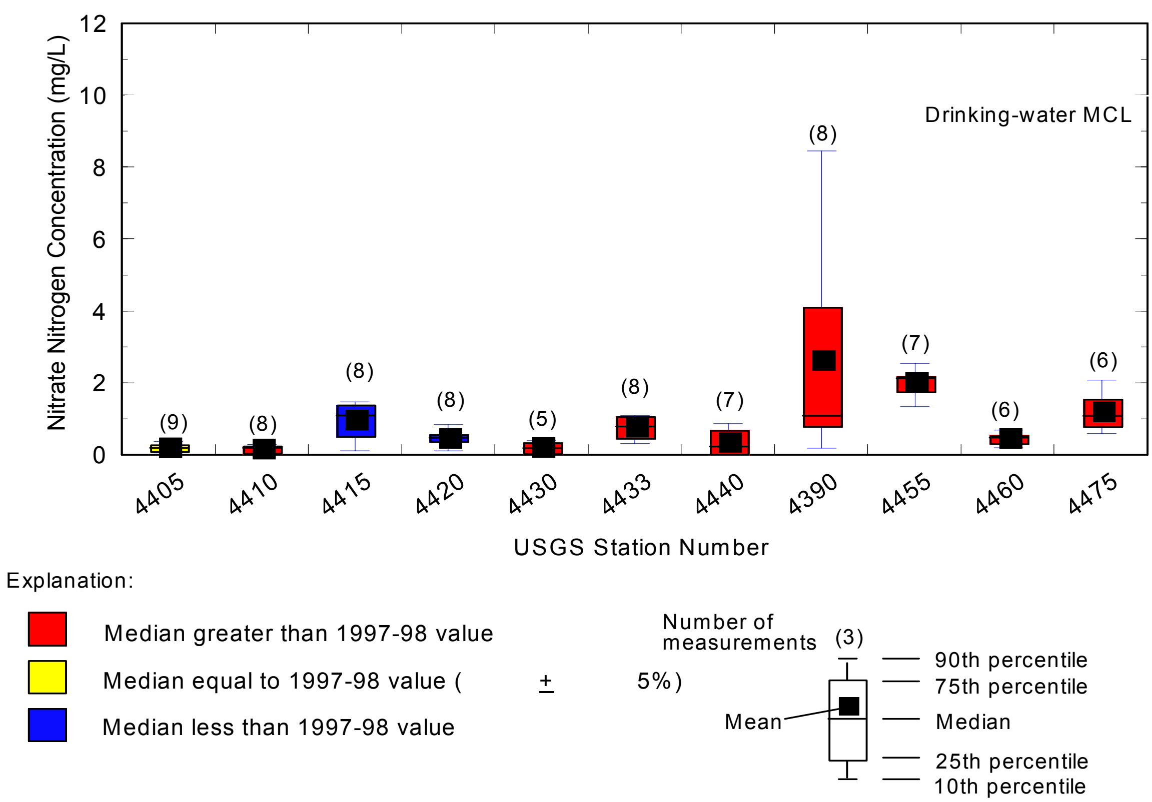


Figure 23: Specific Conductance for Tributary Monitoring Stations 2001

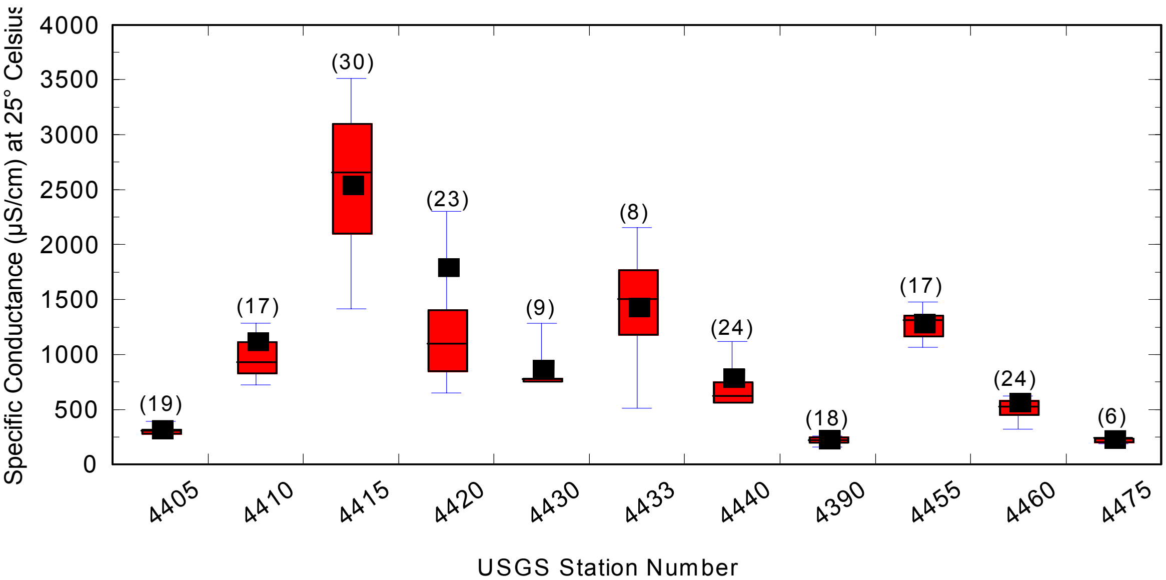
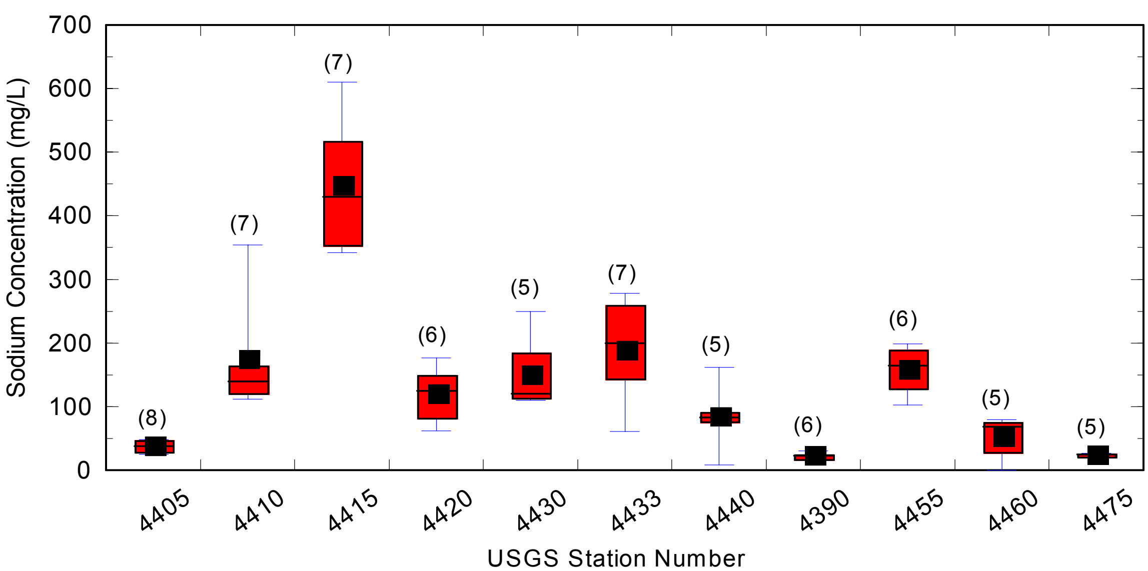


Figure 24: Sodium Concentrations for Tributary Monitoring Stations 2001



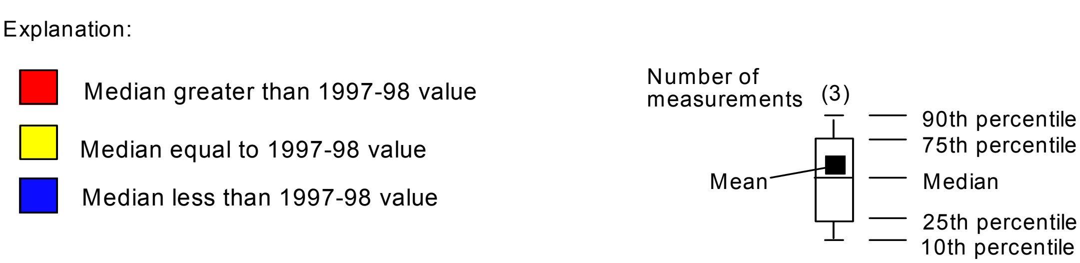


Figure 25: Sodium Yields by Subbasin

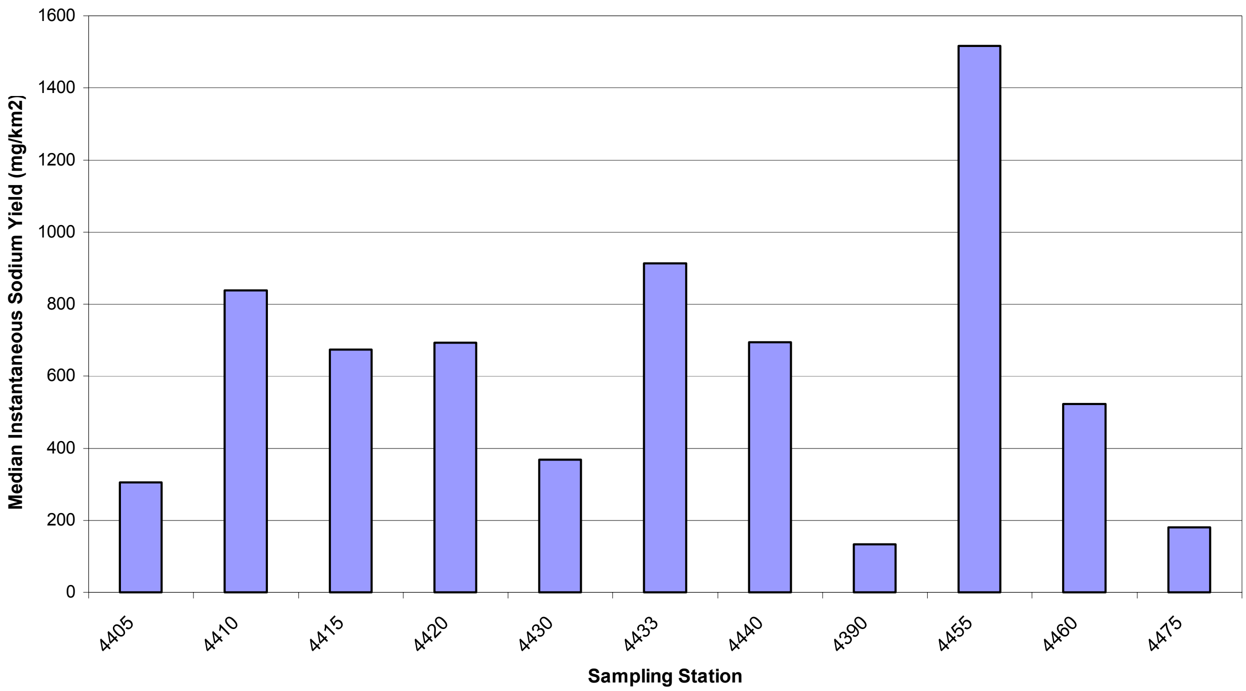


Figure 26: Total Nitrogen Yields by Subbasin

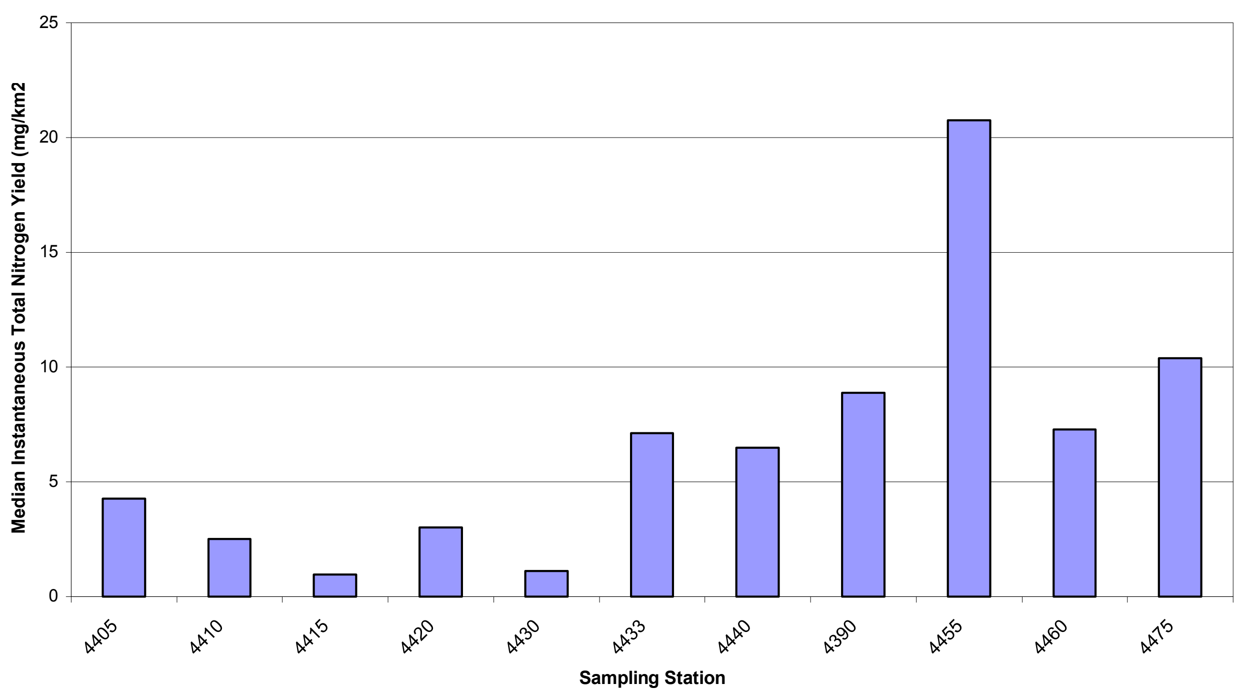


Figure 27: Manganese Yields by Subbasin

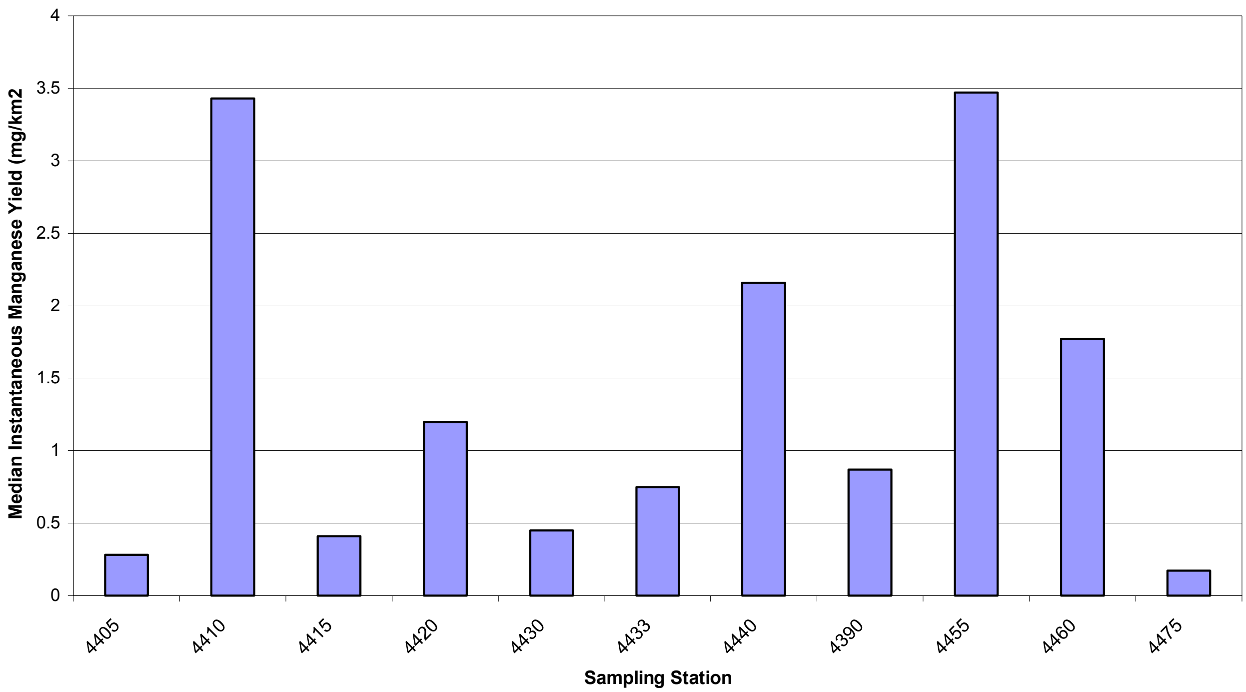
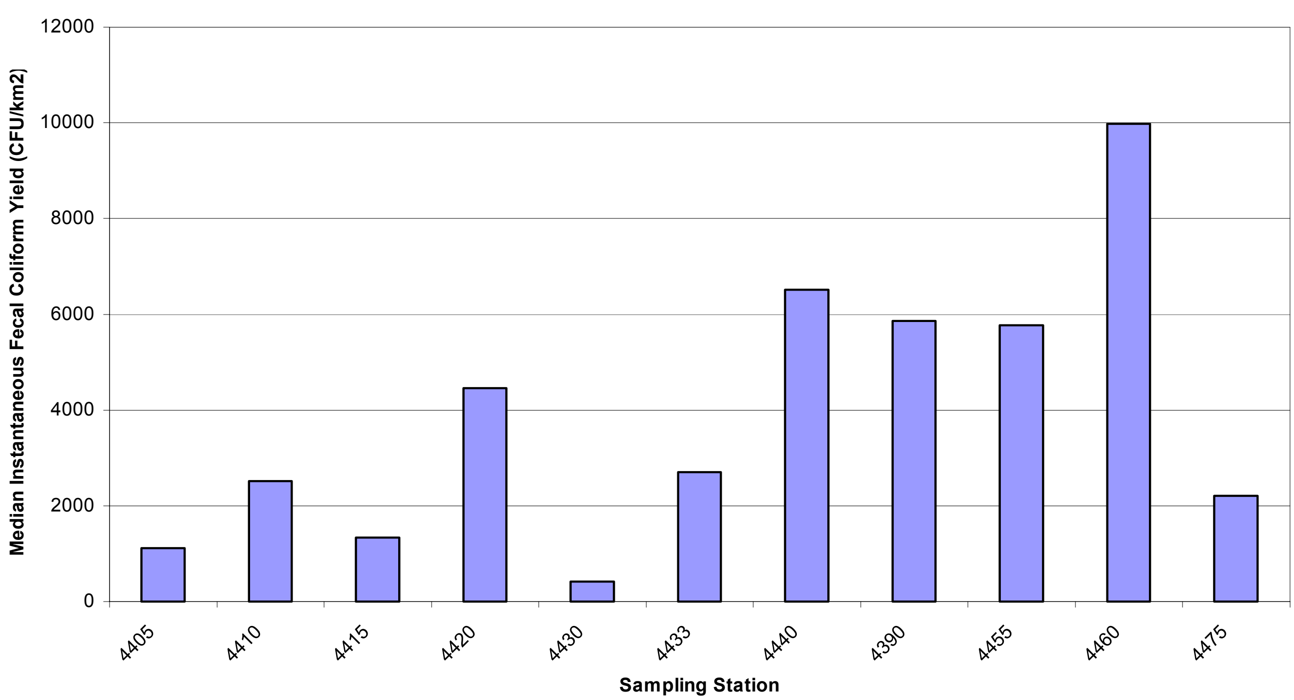


Figure 28: Fecal Coliform Yields by Subbasin



Wet Weather Monitoring

Samples analyzed for nutrients, major ions, and dissolved selected metals were collected during one to three storm events throughout the year at several monitoring stations that were identified in the 1998 USGS study as recipient sites for urban runoff. Event sample collection was conducted in January, March, and July of 2001. Instantaneous yields of several constituents that were sampled during these storms were compared to those collected during baseflow conditions and are presented in bar charts below. As these charts depict, for almost all parameters analyzed concentrations of measured constituents were much higher during storms. The two most extreme examples are fecal coliform bacteria and sodium. However, nutrients and metals (e.g. manganese) are also mobilized during storms and enter the tributaries via surface water runoff from impervious, developed surface areas throughout the watershed. These data illustrate the importance of a detailed storm water monitoring program that will provide extensive characterization of how storms affect water quality and how watershed management practices should be directed in order to mitigate some of these storm water quality impacts.

Figure 29: Fecal Coliform Storm Yields Comparison

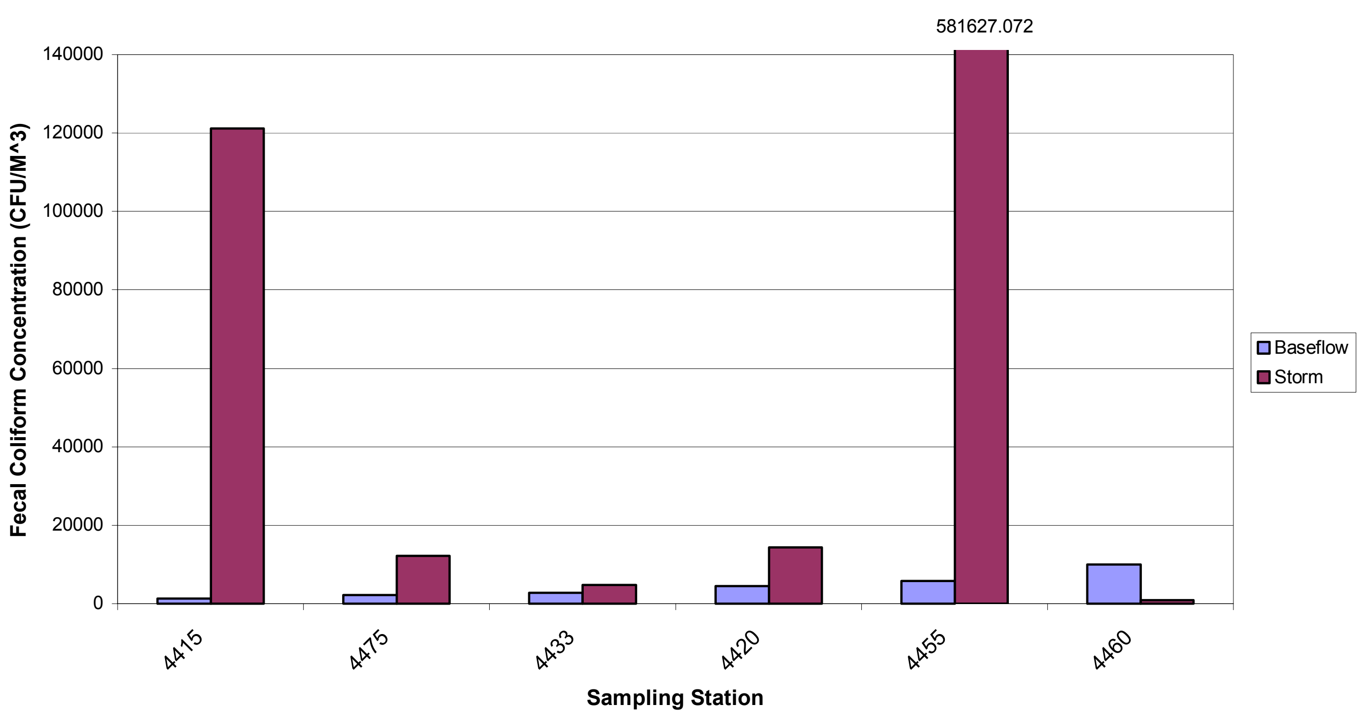


Figure 30: Nitrogen Storm Yields Comparison

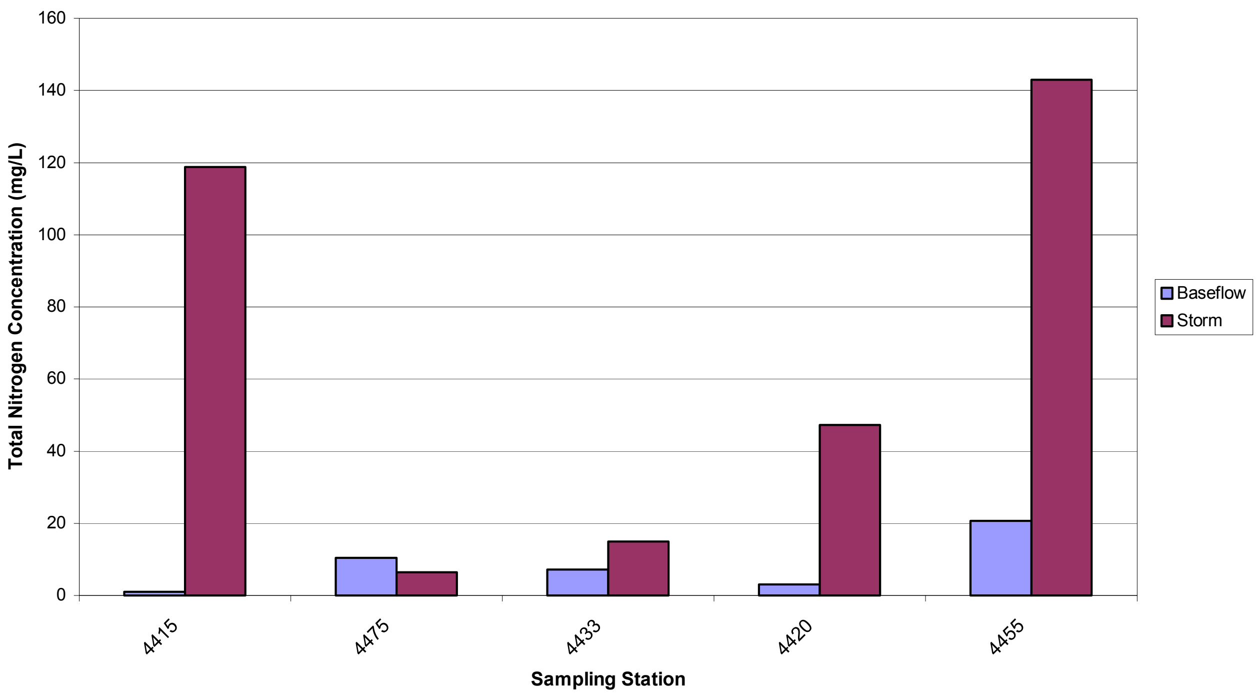


Figure 31: Manganese Storm Yields Comparison

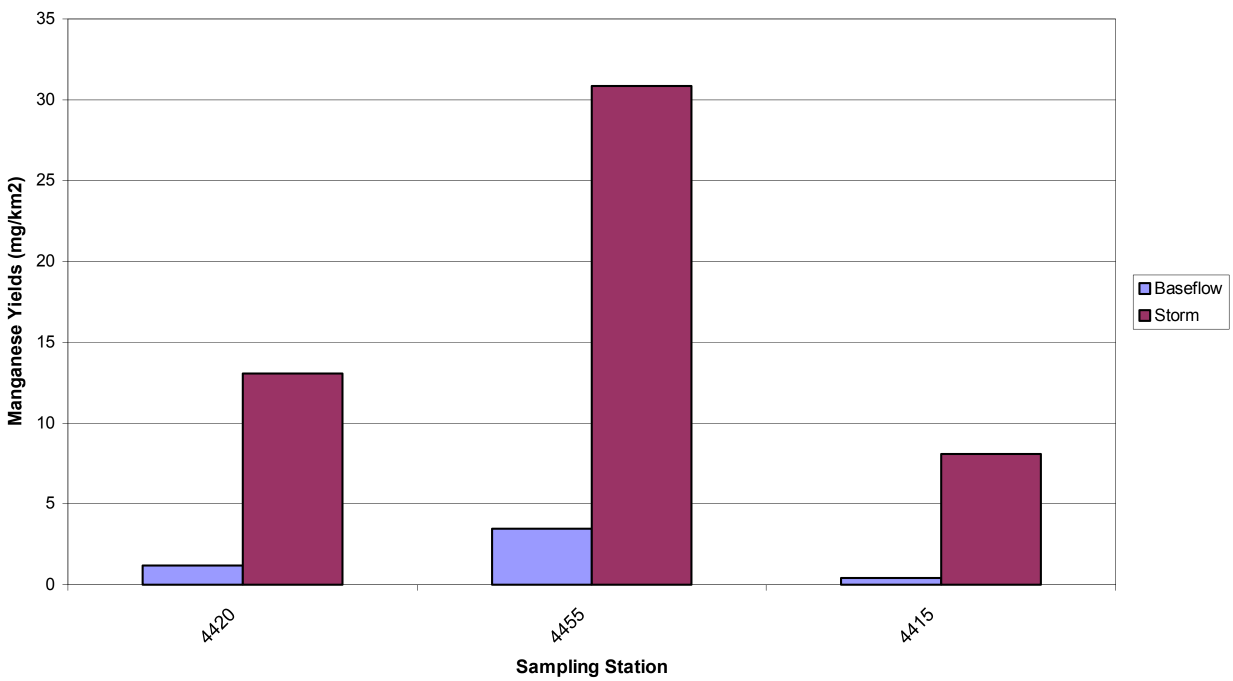


Figure 32: Sodium Storm Yields Comparison

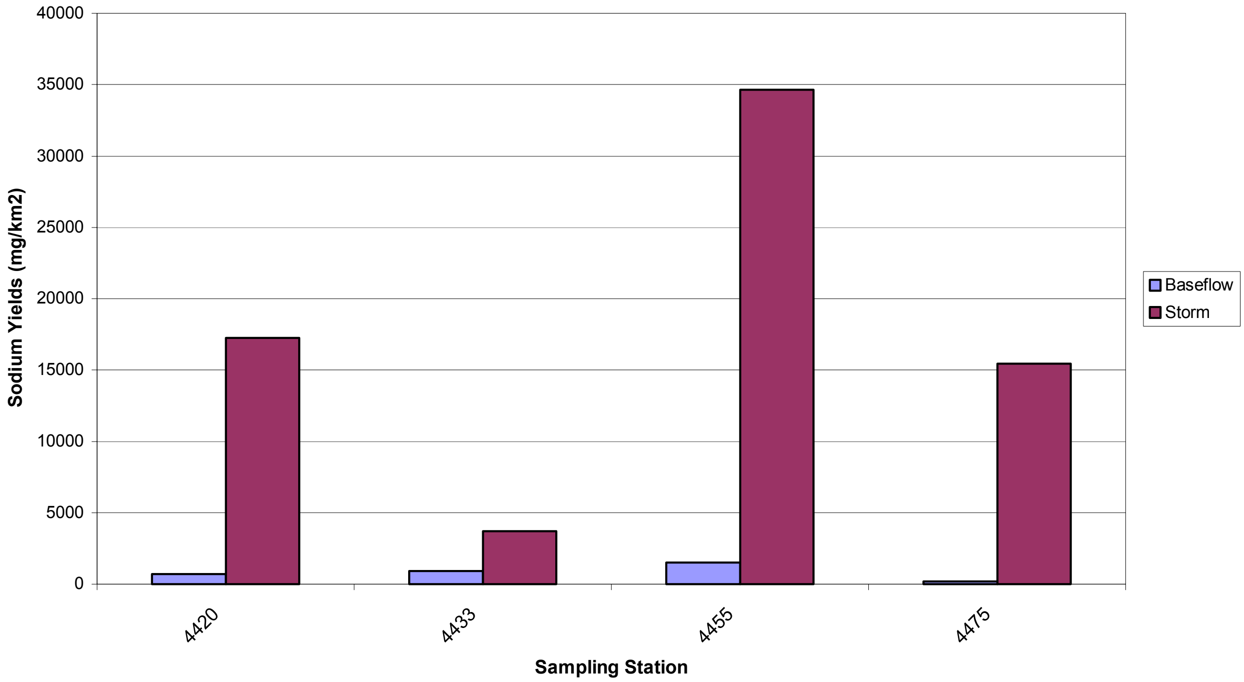


Table 1: Summary of Tributary Water Quality Data

	Sampling Station										
	4390	**4405**	**4410**	**4415**	**4420**	**4430**	**4433**	**4440**	**4455**	**4460**	**4475**
Subbasin Properties											
Baseflow:					**Fecal Coliform**						
Concentration:											
Max	450	250	676	920	580	20	1800	308	220	500	156
Min	16	8	6	0	8	0	0	10	28	20	16
Median	30	24	117	107	60	12	168	65	70	230	22
Average	109	64	229	221.833	176	11	470	124	102.667	238	51.6
Load (kg/d)	157735.9	6252.35	2293.66	1421.5	8427.08	7425.8	2922.29	142745	6931.95	569082.7	4859.16
Yield (kg/km2/d)	5863.788	118.4883	2520.51	1341.04	4458.772	417.1796	2705.828	6518.036	5776.627	9983.908	2208.71
Storm:											
Concentration:											
Max	N/A	N/A	N/A	5520	4800	N/A	4600	N/A	4960	N/A	206
Min	N/A	N/A	N/A	200	28	N/A	26	N/A	100	N/A	132
Median	N/A	N/A	N/A	570	679	N/A	85	N/A	2000	N/A	150
Average	N/A	N/A	N/A	1544	1546.5	N/A	949	N/A	2080	N/A	162.667
Load (kg/d)	N/A	N/A	N/A	128479	27016.49	N/A	5150.21	N/A	697952.5	N/A	26732.64
Yield (kg/km2/d)	N/A	N/A	N/A	121206.6	14294.44	N/A	4768.714	N/A	581627.1	N/A	12151.2
Baseflow:					**Manganese**						
Concentration:											
Max	0.44	0.07	0.73	0.64	0.24	0.83	0.6	0.55	0.77	0.36	0.04
Min	0.06	0.02	0.32	0.09	0.08	0.07	0.16	0.06	0.29	0.1	0.005
Median	0.17	0.06	0.495	0.29	0.19	0.115	0.26	0.25	0.335	0.27	0.02
Average	0.23	0.05	0.51	0.319	0.18	0.283	0.29	0.27	0.425	0.26	0.02
Load (kg/d)	23.47463	1.56	3.43	0.43	2.26	8	0.81	47.21	4.16	101.1	0.38
Yield (kg/km2/d)	0.872663	0.279622	3.77	0.41	1.195598	0.449283	0.749871	2.155827	3.46987	1.773625	0.172475
Storm:											
Concentration:											
Max	N/A	N/A	N/A	0.66	1.5	N/A	1.6	N/A	1.7	N/A	2.4
Min	N/A	N/A	N/A	0.38	0.16	N/A	0.72	N/A	0.14	N/A	0.09
Median	N/A	N/A	N/A	0.39	0.355	N/A	1.16	N/A	0.34	N/A	1.245
Average	N/A	N/A	N/A	0.477	0.593	N/A	1.16	N/A	0.63	N/A	1.245
Load (kg/d)	N/A	N/A	N/A	8.57	24.69	N/A	0.46	N/A	37.01	N/A	26.13
Yield (kg/km2/d)	N/A	N/A	N/A	8.08	13.06124	N/A	0.429064	N/A	30.84289	N/A	11.87521
Baseflow:					**Sodium**						
Concentration:											
Max	31	49	170	630	180	250	280	170	200	80	27
Min	18	33	110	340	60	110	41	0.72	100	0.51	21
Median	23	47	140	430	110	120	200	83.5	165	62.5	25
Average	23.17	43.8	140	447.143	116.6	150	188.71	84.62	158.333	53.42	24.4
Load (kg/d)	3607.277	1703.54	763.14	713.58	1308.24	6566.67	986.84	15191.68	1819.07	29768.89	398.42
Yield (kg/km2/d)	134.0995	304.8475	838.61	673.19	692.1884	368.9138	913.7412	693.684	1515.893	522.2612	181.0988
Storm:											
Concentration:											
Max	N/A	N/A	N/A	1600	360	N/A	340	N/A	1500	N/A	N/A
Min	N/A	N/A	N/A	23	66	N/A	180	N/A	29	N/A	N/A
Median	N/A	N/A	N/A	400	213	N/A	260	N/A	150	N/A	N/A
Average	N/A	N/A	N/A	605.75	213	N/A	260	N/A	559.667	N/A	N/A
Load (kg/d)	N/A	N/A	N/A	18582.05	32619.25	N/A	4004.99	N/A	41549.24	N/A	N/A
Yield (kg/km2/d)	N/A	N/A	N/A	17530.24	17258.86	N/A	3708.326	N/A	34624.37	N/A	N/A

Table 1 Continued: Summary of Tributary Water Quality Data

	Sampling Station										
	4390	4405	4410	4415	4420	4430	4433	4440	4455	4460	4475
Subbasin Properties											
Baseflow:					**Nitrate**						
Concentration:											
Max	9.3	0.3	0.3	1.5	0.9	0.4	1.1	0.9	2.6	0.7	2.1
Min	0.8	0.05	0.05	0.05	0.05	0.05	0.3	0.05	1.3	0.21	0.6
Median	1.15	0.2	0.15	1.1	0.48	0.2	0.8	0.24	2.15	0.45	1.1
Average	3.07	0.16	0.163	0.979	0.46	0.213	0.78	0.36	2.033	0.45	1.22
Load (kg/d)	145.9391	7.25	0.62	0.79	2.17	6.22	4.81	53.33	23.09	180.99	11.72
Yield (kg/km2/d)	5.425246	1.296798	0.68	0.75	1.150651	0.349347	4.457274	2.435374	19.23891	3.175208	5.328707
Storm:											
Concentration:											
Max	N/A	N/A	N/A	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Min	N/A	N/A	N/A	0.7	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Median	N/A	N/A	N/A	0.85	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Average	N/A	N/A	N/A	0.85	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Load (kg/d)	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Yield (kg/km2/d)	N/A	N/A	N/A	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Baseflow:					**Ortho Phosphate**						
Concentration:											
Max	0.01	0.03	0.07	0.06	0.03	0.01	0.26	0.04	0.01	0.02	0.02
Min	0.01	0.005	0.01	0.01	0.01	0.005	0.01	0.01	0.005	0.01	0.005
Median	0.01	0.01	0.015	0.02	0.02	0.005	0.02	0.01	0.008	0.01	0.01
Average	0.01	0.014	0.028	0.027	0.022	0.006	0.06	0.02	0.008	0.01	0.011
Load (kg/d)	1731.572	181.23	0.08	22.65	135.92	368.83	93.45	1918.46	69.09	6255.18	189.72
Yield (kg/km2/d)	64.37072	32.41995	0.09	21.37	71.91568	20.72058	86.52356	87.60106	57.57749	109.74	86.23753
Storm:											
Concentration:											
Max	N/A	N/A	N/A	0.031	0.015	N/A	N/A	N/A	0.17	N/A	206
Min	N/A	N/A	N/A	0.0025	0.003	N/A	N/A	N/A	0.0025	N/A	132
Median	N/A	N/A	N/A	0.02	0.005	N/A	N/A	N/A	0.0063	N/A	150
Average	N/A	N/A	N/A	0.017833	0.007	N/A	N/A	N/A	0.0463	N/A	162.6667
Load (kg/d)	N/A	N/A	N/A	1.33	0.04	N/A	N/A	N/A	0.33	N/A	0
Yield (kg/km2/d)	N/A	N/A	N/A	1.25	0.020788	N/A	N/A	N/A	0.278861	N/A	0
Baseflow:					**Nitrogen**						
Concentration:											
Max	9.59	0.72	0.87	1.8	1.16	0.82	1.64	1.32	2.603	0.92	2.103
Min	1.37	0.3	0.4	0.33	0.48	0.33	0.54	0.33	1.303	0.53	0.903
Median	1.39	0.66	0.695	1.36	0.72	0.495	1.4	0.64	2.296	0.76	1.17
Average	3.44	0.538	0.665	1.236	0.8	0.535	1.33	0.77	2.172	0.75	1.444
Load (kg/d)	238.5733	23.92	2.52	1.02	5.71	19.84	7.7	142.21	24.9	414.95	22.86
Yield (kg/km2/d)	8.868895	4.279433	2.77	0.96	3.020459	1.114735	7.131639	6.493728	20.75397	7.279852	10.39098
Storm:											
Concentration:											
Max	N/A	N/A	N/A	1	19	N/A	N/A	N/A	1	N/A	N/A
Min	N/A	N/A	N/A	0.2	0.05	N/A	N/A	N/A	0.43	N/A	N/A
Median	N/A	N/A	N/A	0.7	0.55	N/A	N/A	N/A	0.5	N/A	N/A
Average	N/A	N/A	N/A	0.633	5.0375	N/A	N/A	N/A	0.608	N/A	N/A
Load (kg/d)	N/A	N/A	N/A	125.95	89.37	N/A	N/A	N/A	171.48	N/A	N/A
Yield (kg/km2/d)	N/A	N/A	N/A	118.92	47.28606	N/A	N/A	N/A	142.9029	N/A	N/A

Class-B Waters on Fresh Pond Reservation

As part of the Fresh Pond Reservation Master Plan implementation, water quality monitoring was conducted at three small ponds within the Fresh Pond Reservation. Black's Nook, Little Fresh Pond, and North Pond are the water bodies involved in this study. Each of the ponds abuts the Cambridge Municipal Golf Course which is technically part of the Fresh Pond Reservation. These Ponds are considered to be an important component of the ecosystem that protects the water quality in Fresh Pond Reservoir. Under the Massachusetts State regulations, these ponds are considered to be Class B water bodies, thus that they are meant to support primary contact recreation, and are not considered to be part of the drinking water supply. There are no surface water connections between Fresh Pond Reservoir and any of these ponds, however the potential exists for groundwater communication between them. Baseline data is collected in order to determine the existing conditions in each pond, how these conditions are changing over time, and how the ponds should be managed in the future in order to optimize the health of each ecosystem with the overall goal of protecting water quality in Fresh Pond Reservoir.

The same techniques that were applied to limnological monitoring of the reservoirs were also used for monitoring of these ponds, and the same analyses on water quality were conducted in order to begin the annual collection of baseline water quality data. These ponds however, are physically, chemically, and ecologically different from any of the reservoirs in the drinking water supply. The average depth in the ponds is approximately 6 feet. Hand-held depth sonar transects were conducted to locate the deepest point in each pond where measurements throughout the water column are taken and where sampling is carried out. Water quality monitoring was conducted on April 13th, May 16th, June 28th, August 28th, and November 8th, in 2001.

The box charts below depict the range of constintuent concentrations measured in sample analysis from each pond on the Fresh Pond Reservation. Black's Nook showed the highest median concentration of fecal coliform bacteria of the three ponds analyzed, with North Pond showing the second highest. This may be a result of the habitat value of these two ponds above that of Little Fresh Pond. North Pond and Black's Nook in particular, is protected with surrounding trees and provides ideal aquatic habitat for mammals and birds. This may be the cause of relatively higher fecal concentration values.

Black's Nook also displayed the highest orthophosphate median concentration throughout the three ponds. Birds were identified in the 1998 USGS study as a potential source of orthophosphate in the watershed, thus Black's Nook, offering the most habitat of the three ponds, might attribute it's elevated nutrients to this. Past golf course practices may have also had an impact on water quality in the pond. Little Fresh Pond displayed the highest nitrate concentrations which may be attributed to the adjacent golf course – of the three ponds, Little Fresh is in the closest proximity to actively maintained turf grass. Little Fresh Pond also had the highest sodium concentrations which may be a result of treated water being diverted into the pond for irrigating the golf course during dry periods; sodium hypochlorite is a chemical used in the treatment of drinking water.

Little Fresh Pond also had the highest chlorophyll concentrations and associated TSI value. This means that the greatest algal productivity was observed in this pond. Black's Nook and North Pond, although had lower chlorophyll values, were choked with aquatic weeds during much of the growing season thus although sample results may not indicate an advanced eutrophic state in these ponds, they exhibit the typical over-production of biomass associated with the eutrophication process. Lower chlorophyll concentrations in Black's Nook and Little Fresh may be a result of other aquatic weeds blocking sunlight or temporarily up-taking nutrients available in the water column, limiting the growth of free-floating algae.

Data collected on these ponds next year will be compared to the 2001 results to further determine the long-term condition of these water bodies. These data will be used to guide ecological recovery efforts for the Fresh Pond Reservation which protects Fresh Pond from threats caused by the surrounding urban environment.

Figure 33: Fresh Pond Reservation Class B Waters – Fecal Coliform Concentrations

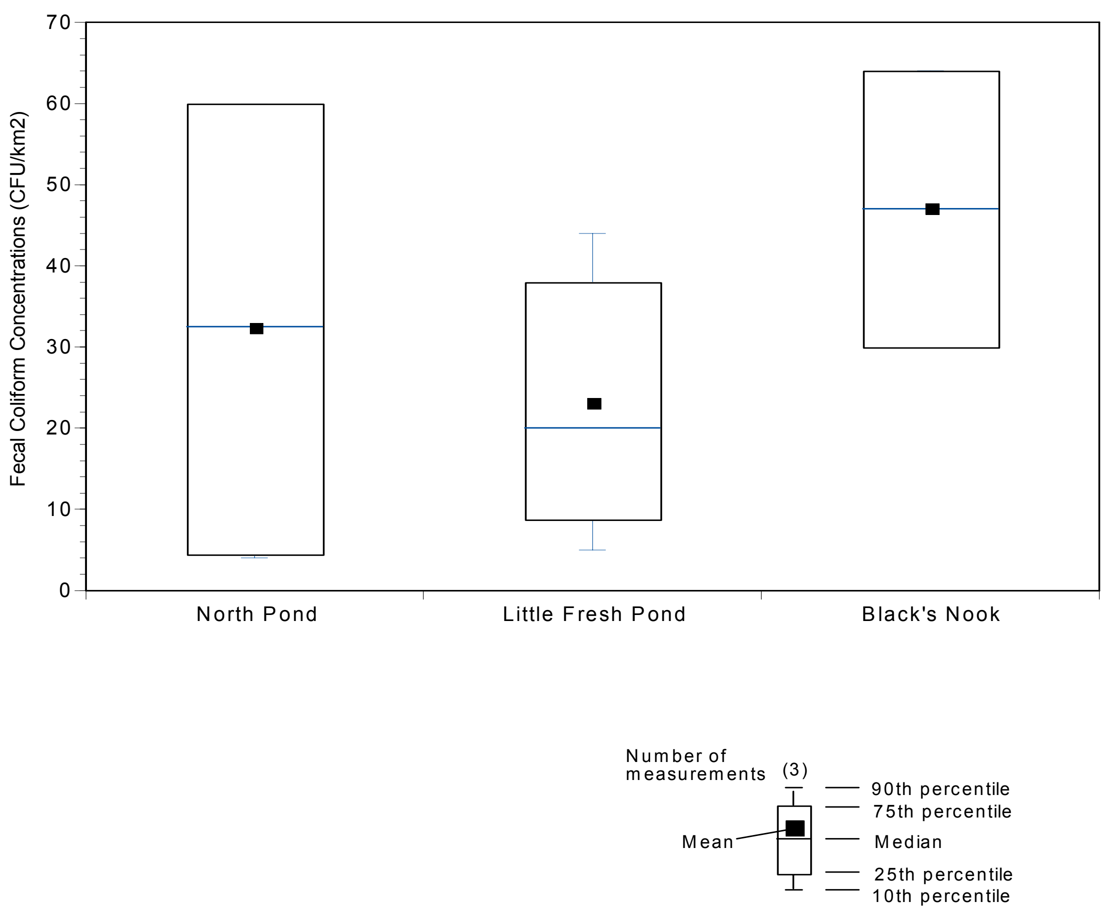


Figure 34: Fresh Pond Reservation Class B Waters – Orthophosphate Concentrations

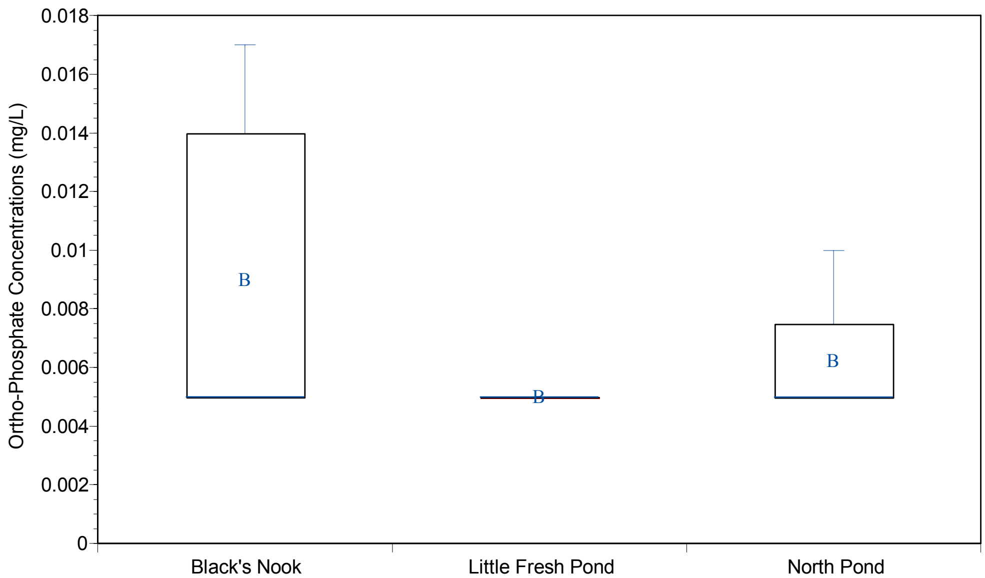
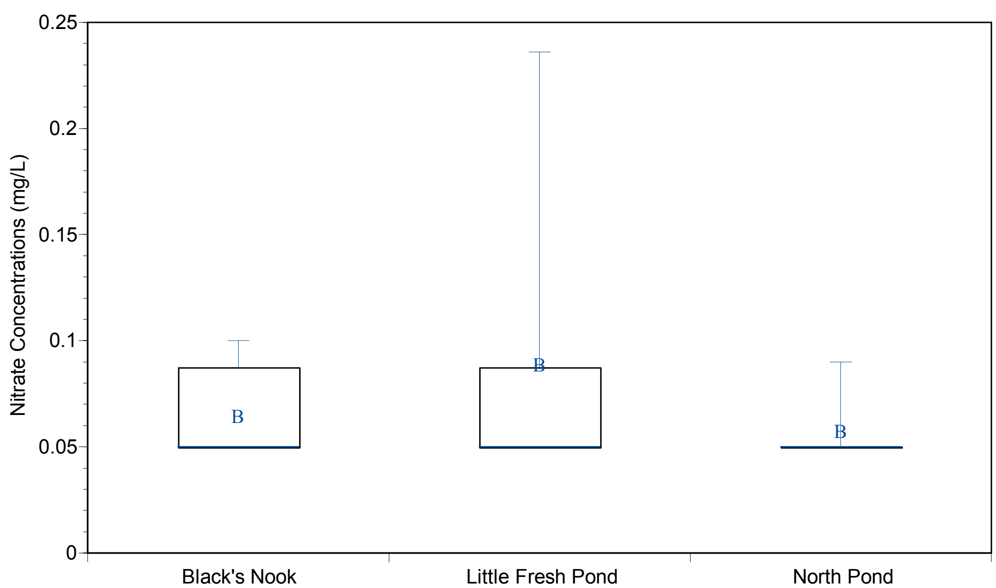


Figure 35: Fresh Pond Reservation Class B Waters – Nitrate Concentrations



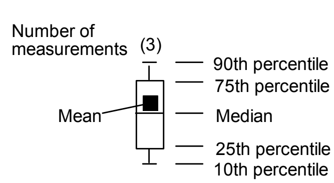


Figure 36: Fresh Pond Reservation Class B Waters – Sodium Concentrations

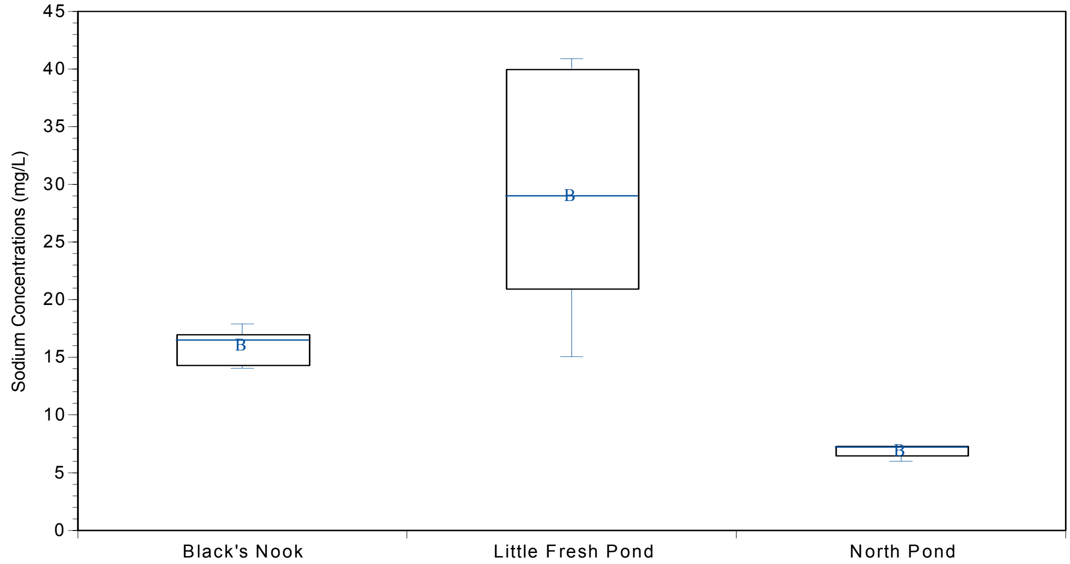
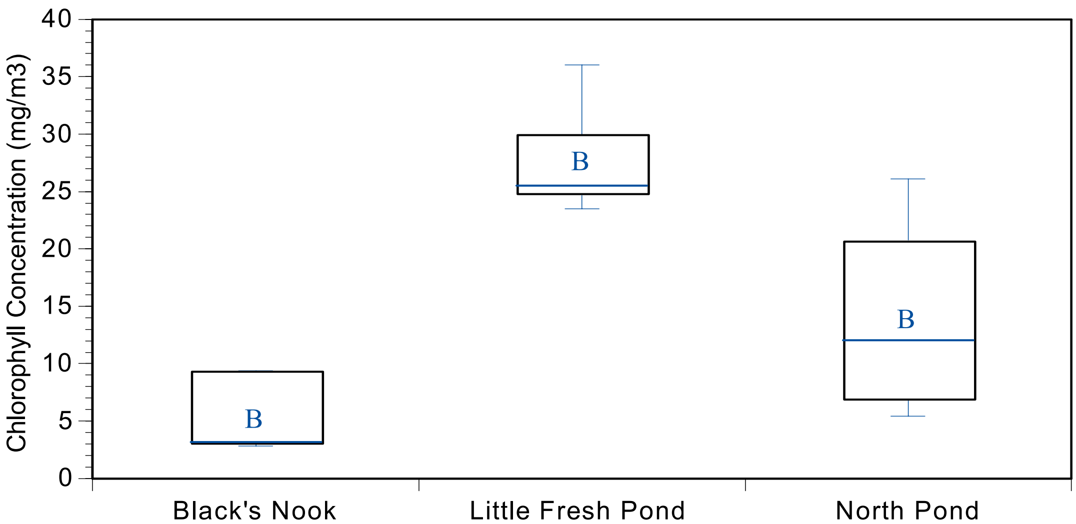
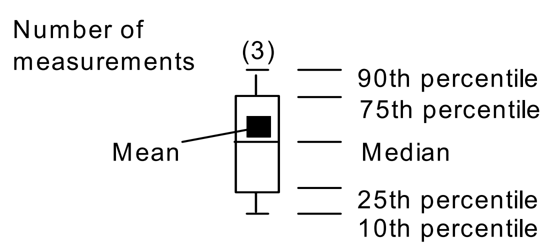


Figure 37: Fresh Pond Reservation Class B Waters - Chlorophyll Concentrations

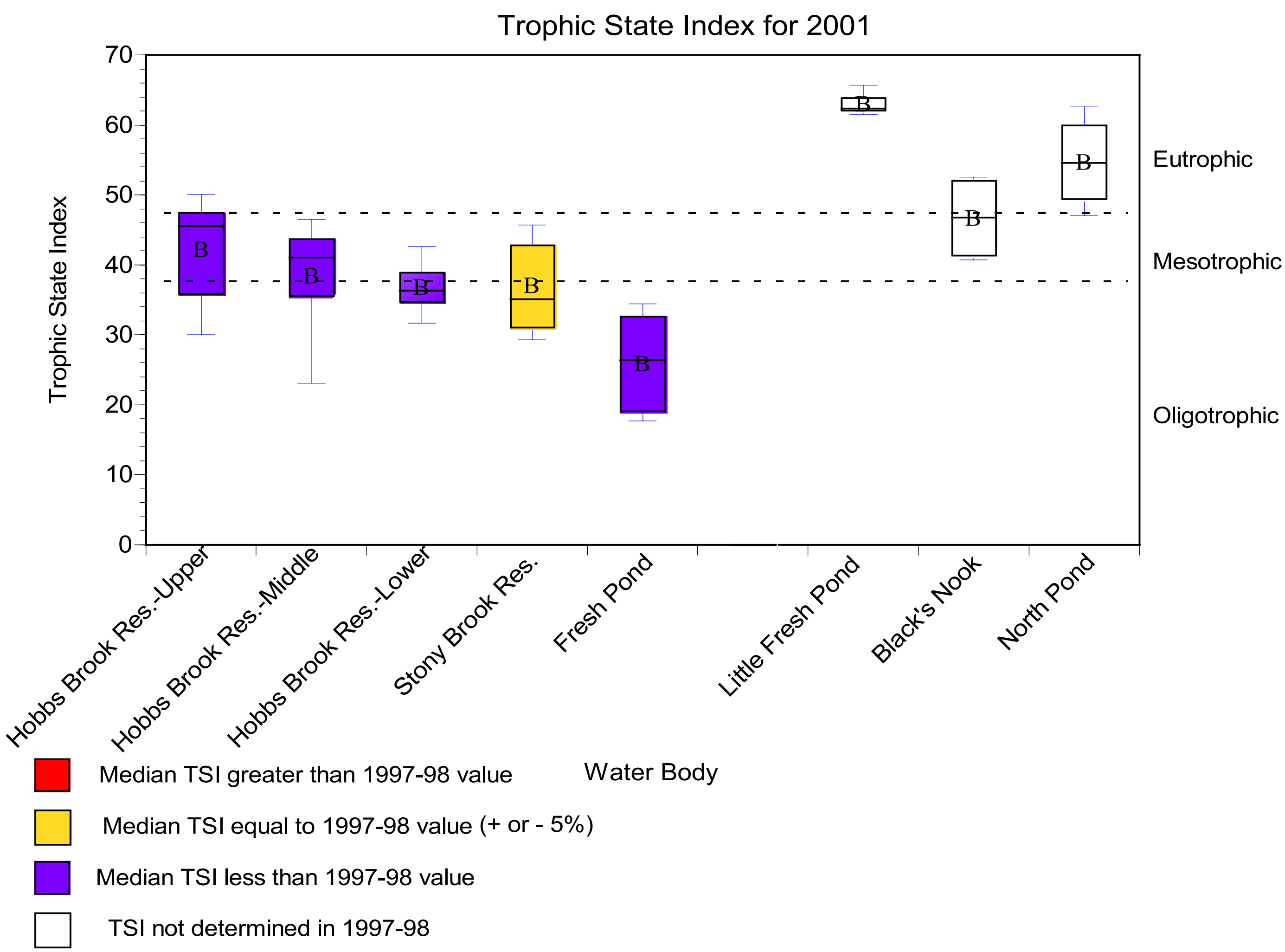




The chart below displays the calculated trophic state indices for the drinking water supply and for the water bodies at Fresh Pond Reservation. The chart shows the apparent cascade effect that is inherent in the water supply, in which contaminants sequentially settle out of the water column before passing to the next reservoir resulting in low nutrient concentrations in Fresh Pond which allows the pond to remain oligotrophic, which is the desired biological state for a water supply.

With the exception of Stony Brook Reservoir, whose trophic state did not significantly change since the 1998 Study, all other reservoirs displayed a lower trophic state value. This is a positive trend that supports the long-term health of the source waters, and indicates that nutrient loading for the study year did not pose a threat to the drinking-water supply.

Figure 38: Surface Waters in Cambridge Source Water Area - Trophic State Index



Special Water Quality Investigations

The water quality monitoring program includes the investigation of specific point-source locations that contribute contaminants to the water supply. These locations are not tributary sampling stations, rather outfalls, or elicit discharges that enter tributaries, whose sources were detected by routine or stormwater sampling in the tributaries and traced back upstream to their specific location. During this study period one location was regularly investigated as a result of water quality degradation detected at routine sampling stations: an illicit sewage discharge at a detention basin in Waltham.

Illicit Discharge in Waltham

Data collected at the sewage discharge location were shared with the City of Waltham who responded with investigating the infrastructure in the immediate area. An ongoing effort is underway to understand what is causing this elicit release, which occurs only on occasion. Until this issue is completely resolved, sampling at this site for fecal coliform bacteria will continue.

Data Table for Fecal Coliform Samples Collected at Costco drainage ditch in Waltham, MA

Sampling Date	Fecal Coliform Concentration mg/100ml
5-Jan-01	1000000
9-Jan-01	180000
9-Jan-01	19200
11-Jan-01	2200
11-Jan-01	32
1-Mar-01	4
1-Mar-01	267
30-Nov-01	50800
24-Dec-01	40
9-Jan-02	2560
24-Jan-02	344000
8-Feb-02	13300
20-Feb-02	4300
22-Feb-02	0
28-Feb-02	5000
18-Mar-02	8200
27-Mar-02	1600
8-Apr-02	271
18-Apr-02	112
6-May-02	262
24-May-02	534
16-Jun-02	336
26-Jun-02	1232
2-Jul-02	1038

Water Balance Discussion

The water balance, which defines the balance between water gains (inflow components) and losses (outflow components) over a given period of time, is a useful tool for general management decisions. The water balance determined for Hobbs Brook Reservoir during water year 2001 can be considered a generalized approximation of the overall water availability. Since continuous gaging data was only available at three monitoring stations during this study, total system output is a rough estimate. At the station immediately downstream of Hobbs Brook Reservoir, an approximate 2.912 billion gallons of outflow from the reservoir was measured. This volume is larger than the estimated total storage capacity of the reservoir which is 2.497 billion gallons. This large volume of water, despite the fact that the City's supply was off-line for some duration of the study, can be attributed to the spring floods that occurred during the year. The hydraulic detention time can be defined as the time it would take for the reservoir to empty out if all inputs of water to the reservoir ceased. Dividing the total estimated reservoir volume by the total estimated reservoir outflow produces a total estimated detention time of 0.86 years (approximately 10 months) for 2001.

Inputs to Stony Brook Reservoir were contributed mostly by the watershed, including station 4455 or WA-17, which totalled approximately 214.4 million gallons for water year 2001, and partially from the Hobbs Brook Reservoir. Outlfow from the Cambridge source water area to the Charles River was estimated using the gaging station located at the Stony Brook Gatehouse. The total outflow to the Charles for water year 2001 was 6.425 billion gallons, significantly greater than the total estimated reservoir capacity of 255 million gallons. This can be attributed to the large watershed area that drains the Stony Brook Reservoir. In addition to the volume of water that passes through the overflow structure to the Charles River, the gates to the gatehouse were opened to allow water into Fresh Pond in Cambridge, in order to meet demand.

The best estimate of water sent to Cambridge from Stony Brook Reservoir is based on the annual water usage from the treatment plant which was 3.13 billion gallons. This should be added to the 6.425 billion gallons flowed to the Charles River in order to determine total output from the source water area. Based on these assumptions, total output from Stony Brook Reservoir is 9.56 billion gallons. Using this value, the total estimated detention time in Stony Brook Reservoir was 0.0267 years, or approximately 10 days for 2001. This indicates a high flushing rate which is a result of the large amount of precipitation received in the spring. With 3.13 billion gallons as total estimated output from Fresh Pond to the treatment plant, the total estimated detention time of Fresh Pond was 0.495 years or close to six months for water year 2001. It should be noted that under normal operating conditions, this number is most likely smaller since the treatment plant was not operational during a significant portion of this study.

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Glossary

Algal bloom—The rapid proliferation of passively floating, simple plant life in and on a body of water.

Anoxic—The absence of oxygen; anaerobic.

Atmospheric deposition—The transfer of substances from the atmosphere to the surface of the Earth or to objects on its surface. Transfer can be either by wet-deposition processes (rain, snow, dew, fog, frost, hail) or by dry deposition (gases, aerosols, fine to oarse particles) in the absence of water.

Bed sediment —The material that temporarily is stationary in the bottom of a stream or other water body.

Colony-forming units (CFU)—Unit of bacterial population size referring to the colonies that appear on a nutrient-agar plate following inoculation of the plate with a sample of water. Each colony may arise from a single bacterial cell or from a small cluster of cells; hence, the colony is reported as a CFU and the bacterial population density is reported as the number of CFUs per unit volume (usually 100 milliliters) of water.

Contamination—Change of water quality by the addition of constituents as a result of human activity or natural processes.

Constituent—A compound such as a chemical species or biological population whose magnitude in water, sediment, biota, or other matrix is determined by an analytical method.

Correlation coefficient—A statistic that can be used to measure the strength of a relation between two variables.

Discharge (hydraulics)—Rate of flow, especially fluid flow; a volume of liquid passing a point per unit of time, commonly expressed in cubic feet per second, million gallons per day, or liters per second.

Dissolved oxygen (DO)—Oxygen dissolved in water; one of the most important indicators of the condition of a water body. Dissolved oxygen is necessary for the life of fish and most other aquatic organisms.

Drainage basin—Land area drained by a river or stream; watershed.

Epilimnion—Warm, oxygen-rich, upper layer of water in a lake or other body of water, usually seasonal. *See also* Metalimnion, Hypolimnion

Eutrophic—Term applied to a body of water with a high degree of nutrient enrichment and high productivity.

Eutrophication—Process by which water becomes enriched with plant nutrients, most commonly phosphorus and nitrogen.

Fecal coliform bacteria—Group of several types of bacteria that are found in the alimentary tract of warm-blooded animals. The bacteria commonly are used as an indicator of animal and fecal contamination of water.

Ground water—In the broadest sense, all subsurface water, as distinct from surface water; as more commonly used, that part of the subsurface water in the saturated zone. *See also* Surface water.

Hypolimnion—Cold, oxygen-poor, deep layer of water in a lake or other water body. *See also* Epilimnion, Metalimnion.

Hypoxic—The near absence of oxygen.

Kettle-hole lake—Glacially-formed lake with no surfacewater inflows or outflows.

Limnology—Scientific discipline dealing with the physics, chemistry, and biology of inland waters such as lakes, ponds, reservoirs, streams, and wetlands.

Load—Material that is moved or carried by streams, reported as the weight of the material transported during a specific time period, such as kilograms per day or tons per year.

Main stem—The main trunk of a river or stream.

Maximum contaminant level (MCL)—Maximum permissible level of a contaminant in water that is delivered to any user of a public water system, established by a regulatory agency such as the U.S. Environmental Protection Agency. *See also* Secondary maximum contaminant level.

Mean—The arithmetic average obtained by dividing the sum of a set of quantities by the number of quantities in the set.

Median—The middle or central value in a distribution of data ranked in order of magnitude. The median also is known as the 50th percentile.

Mesotrophic—Term applied to a body of water with intermediate nutrient content and intermediate productivity.

Metalimnion—Transition zone between the warm upper layer and the cold deep layer of a lake or other water body, characterized by rapidly decreasing temperature with increasing depth. *See also* Epilimnion, Hypolimnion.

Minimum reporting limit (MRL)—The lowest measured concentration of a constituent that can be reported reliably using a given analytical method.

Monitoring station—A site on a stream, canal, lake, or reservoir used to observe systematically the chemical quality and discharge or stage of water.

Nutrient—An element or compound essential for animal and plant growth. Common nutrients in fertilizer include nitrogen, phosphorus, and potassium.

Oligotrophic—Term applied to a body of water low in nutrients and in productivity.

pH—The logarithm of the reciprocal of the hydrogen ion concentration of a solution; a measure of the acidity (pH less than 7) or alkalinity (pH greater than 7) of a solution; a pH of 7 is neutral.

Phytoplankton algae—Free-floating, mostly microscopic aquatic plants.

Phytoplankton chlorophyll *a*—Primary light-trapping pigment in most phytoplankton algae. Concentration can be used as an indirect indicator of the abundance of phytoplankton algae in a lake or other water body.

Runoff—That part of precipitation that appears in surface streams. It is equivalent to streamflow unaffected by artificial diversions, storage, or other human works in or on the stream channel.

Secondary maximum contaminant level (SMCL)— Maximum recommended level of a contaminant in water that is delivered to any user of a public water system. These contaminants affect the esthetic quality of the water such as odor or appearance; therefore, the levels are intended as guidelines. *See also* Maximum contaminant level.

Specific conductance—A measure of the ability of a sample of water to conduct electricity.

Subbasin—Drainage basin or watershed defined by a specific monitoring station and representing the land area that contributes water to that station.

Surface water—An open body of water, such as a stream or lake. See also Ground water.

Swamp—A forested wetland that has standing water during most or all of the growing season.

Thermal stratification—Seasonal division of a lake or other water body into a warm upper layer and a cold deep layer that is no longer in contact with the atmosphere. In some lakes, thermal stratification can result in a loss of oxygen in the deep layer and subsequent chemical stratification.

Trihalomethane formation potential (THMFP)— Tendency of naturally occurring organic compounds in a water supply to form toxic trihalomethanes during water treatment.

Trophic state—The extent to which a body of water is enriched with plant nutrients. *See also* Eutrophic, Mesotrophic, Oligotrophic.

Trophic state index (TSI)—A numerical index indicating the degree of nutrient enrichment of a body of water.

Turbidity—The opaqueness or reduced clarity of a fluid due to the presence of suspended matter.

Water year—The continuous 12-month period, October 1 through September 30, in U.S. Geological Survey reports dealing with the surface-water supply. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ending September 30, 1998, is referred to as the “1998” water year.

Wetlands—Lands that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions.

Yield—The weight of material transported during any given time divided by unit drainage area, such as kilograms per day per square kilometer or tons per year per square mile.

Appendix A – Project Description

Monitoring Objectives

The process of designing a water-quality monitoring program begins with a clear definition of program goals and objectives (Reinelt and others, 1988). The goals then guide the entire process of program design and implementation. Ideally, the data obtained through monitoring provide an objective source of information needed to support management decisions. Specifically, an effective water-quality monitoring program will provide quantitative answers to the following questions (Intergovernmental Task Force on Monitoring Water Quality, 1995):

- What is the condition of the source water?
- Where, how, and why are water-quality conditions changing over time?
- What problems are related to source-water quality? Where are the problems occurring and what is causing them?
- Are programs to prevent or remediate problems working effectively?
- Are water-quality goals and standards being met?

The primary goal of the Cambridge drinking water source-area monitoring program is to ensure that water withdrawn from Fresh Pond for treatment is as free as possible from contaminants, thereby minimizing the costs of treatment. Specific objectives of the program are to:

- Monitor the condition of source waters in the Cambridge drinking water supply system;
- Determine where, when, and how water-quality conditions are changing over time;
- Identify actual and potential problems related to source-water quality;
- Evaluate effectiveness of programs to prevent or remediate problems;
- Ensure that all applicable water-quality goals, standards, and guidelines are being met; and
- Provide for rapid response to emerging problems.

Monitoring-Program Elements

The Cambridge source-area monitoring program consists of four major elements: (1) routine monitoring of reservoirs and tributary streams during dry weather, (2) event-based monitoring of streams, storm drains, and other outfalls during wet weather, (3) continuous recording of stage and selected water-quality characteristics at critical sites within the drainage basin, and (4) periodic monitoring of ground water in the vicinity of Fresh Pond.

Routine (Dry Weather) Surface-Water Monitoring

Dry-weather sampling is conducted at 3 primary and 6 secondary reservoir-monitoring stations, and at 11 primary and 5 secondary tributary-monitoring stations. The distinction between primary and secondary monitoring stations is based on the frequency of sampling and on the number of analyses performed on the samples.

The reservoir sampling schedule for this study (table A1) is based on the results of a USGS study which determined that monthly sampling was sufficient to characterize changes in reservoir water quality during the spring, summer, and early autumn months and that sampling every other month was sufficient during winter. At regular intervals (once each month from May through October and every other month from December through April), CWD staff measure Secchi disk transparency and depth profiles of specific conductance, pH, water temperature, turbidity, and dissolved oxygen concentration at both the primary and the secondary reservoir-monitoring stations.

Secchi disk transparency is a measure of the depth of penetration of sunlight in a reservoir. It is measured by lowering a small horizontal disk on a calibrated line and noting the depth at which it is no longer visible from the surface (Lind, 1974). In the Cambridge drinking-water source area, the Secchi disk transparency is related mainly to the abundance of phytoplankton algae in the upper mixed layers of the reservoirs which proliferate relative to nutrient abundance. Thus, Secchi depth readings provide a quick and inexpensive indicator of eutrophication problems. Water temperature, specific conductance, pH, turbidity, and dissolved oxygen concentration were measured *in-situ* with an electronic multiparameter water-quality monitoring system lowered on a cable. Depth profiles of these characteristics provide essential information on physical, chemical, and biological conditions in the reservoirs.

Reservoir Sampling Process Overview

At the three primary reservoir-monitoring stations only (fig. A1), water samples were pumped with a peristaltic pump through pre-cleaned Tygon tubing from three depths—6 ft below the surface, the depth of the thermocline (the point of maximum rate of change in water temperature with depth), and 2 to 6 ft above the bottom—when the water column was thermally stratified. Samples were dipped from below the surface of the pond when limnoligical conditions were isothermal. Water from each sampling depth was collected in accordance with clean-sampling protocols (Wilde and others, 1999) into Teflon bottles. The samples were returned to the CWD laboratory and analyzed for color, alkalinity, and concentrations of major ions (sodium, calcium, chloride, and sulfate), nutrients (ammonia nitrogen, total Kjeldahl nitrogen, nitrate nitrogen, total phosphorus, and orthophosphate phosphorus), selected metals (aluminum, iron, and manganese), and phytoplankton chlorophyll-*a*, using standard methods (American Public Health Association and others, 1995). Studies conducted by the USGS have shown that under most conditions, water-quality data collected in depth profiles at these stations are indicative of conditions throughout the reservoirs.

Color was measured spectrophotometrically on each sample and is primarily an indicator of the concentration of dissolved organic matter, which is abundant in source-area streams and reservoirs, and must be removed during treatment to prevent formation of organochlorine by-products. Alkalinity is a measure of the acid-neutralizing capacity of a water sample and is mainly dependent on the quantities of carbonate and bicarbonate ions. The most accurate indicator of the abundance of phytoplankton algae is the amount of particulate chlorophyll-*a* in the upper mixed layer of the reservoir. Changes in chlorophyll concentrations are indicative of changes in reservoir trophic state – the extent to which a water body is enriched with plant nutrients.

Nitrogen and phosphorus are plant nutrients that can, in sufficient quantities, cause algal blooms in the reservoirs and excessive growth of algae and higher plants in the streams. Ecologically significant forms of nitrogen include ammonia and nitrate nitrogen in runoff from areas that receive fertilizer applications and in wastewater discharges, and organic nitrogen produced by microbial processes. The concentration of organic nitrogen is determined by subtracting the concentration of ammonia nitrogen from that of total Kjeldahl nitrogen (TKN), therefore ammonia and TKN were analyzed in source water samples.

During each round of reservoir sampling, concentrations of fecal coliform bacteria were measured at the withdrawal points in all three reservoirs. The presence of fecal coliform bacteria in a water sample indicates that the water may have been contaminated with feces from humans or other warm-blooded animals. Such contamination can introduce disease- causing viruses and other potential pathogens.

Routine Tributary Monitoring Process Overview

Water entering the reservoirs is monitored at 11 primary and 5 secondary tributary-stream-monitoring stations (fig. A1). These stations represent streams that contribute water directly to the reservoirs and major tributaries, or integrate large areas of the drainage basin. Thus, the stations are important primary indicators of the condition of water likely to enter the reservoirs. Every 2 months, the CWD uses USGS methods (Rantz and others, 1982; Wilde and others, 1999) to measure stage and discharge and to assess water quality at each primary stream-monitoring station. The sampling frequency (table A1), in conjunction with continuous monitoring in each of the three reservoirs (see below), is sufficient to capture changes in water quality in time to prevent contamination problems at the water-treatment plant intake.

Specific conductance, pH, water temperature, turbidity, and dissolved oxygen concentration are measured on site and water samples are collected in accordance with clean-sampling protocols (Wilde and others, 1999) into 1-liter Teflon isokinetic samplers. Discharge-weighted, representative samples are collected from multiple vertical profiles distributed at equal distances along stream cross sections (Edwards and Glysson, 1999). The samples are then returned to the CWD laboratory for analysis of color, fecal coliform bacteria, alkalinity, total suspended solids, and concentrations of major ions, nutrients, and selected metals (table A1).

The five secondary stream-monitoring stations are monitored twice a year, usually during base flow and high flow. These stations are located higher up in the drainage basin on smaller tributaries or at points that discharge to the reservoirs predominantly during wet weather (fig. A1). The secondary stations are sampled biannually for the same constituents as the primary stations to provide indicators of potential changes in water quality or of base-flow conditions.

As with all samples collected during this study, each round of periodic sampling included quality-assurance samples (field and instrument blanks, duplicates, and sample splits) that represent about 10 percent of the total number of samples analyzed. Results from these analyses are out of the scope of this report, but were monitored throughout the field work component to insure that USGS quality control standards were consistently met.

Event-Based (Wet Weather) Surface-Water Monitoring

Storm-event sampling was conducted several times during this study at several sites, some of which are primary and secondary stream-monitoring stations and some of which are pipes and culverts that discharge to the reservoirs (fig. A1). The goal of the storm-event sampling is to collect samples of the first flush of runoff from storms producing 0.5 inches or more of rain after a period of at least 3 days of dry weather. For this study, this goal was accomplished by manually collecting the first flush from, open tributaries, pipes, or culverts. The samples were analyzed for color, fecal coliform bacteria, alkalinity, total suspended solids, and concentrations of major ions, nutrients, and selected metals. These data were compared to results from routine, dry-weather monitoring in order to assess the effects of storms on introducing sediment and associated constitutent loads to the reservoirs. A detailed, multi-year stormwater study is propsoed beginning in 2002 which will provide an in-depth understanding of water quality during storm events that pass through the Cambridge Watershed.

Special Water Quality Investigations

The water quality monitoring program includes the investigation of specific point-source locations that contribute contaminants to the water supply. These locations are not tributary sampling stations, rather outfalls, or elicit discharges that enter tributaries, whose sources were detected by routine or stormwater sampling in the tributaries and traced back upstream to their specific location.

Continuous-Record Surface-Water Monitoring

Continuous (15 minute interval) monitoring is contucted at three primary tributary-monitoring stations and two secondary reservoir-monitoring stations. These stations are operated and maintained by the USGS and CWD for continuous measurement of stream and reservoir stage and temperature-corrected specific conductance. Precipitation also is monitored at two of the stations. Specific conductance, a measure of the ability of the water to conduct an electrical current, is an indicator of the concentrations of dissolved electrolytes in the water. The station at Hobbs Brook Reservoir and Stony Brook Reservoir also monitor stage and specific conductance of the discharges from the reservoirs. This information is uploaded on a real-time basis to the USGS internet site. The continuous stream-stage data are converted to discharge by the use of stage-discharge relations (Rantz and others, 1982) and the specific conductance records are converted to concentrations of sodium, calcium, and chloride in a similar fashion (Granato and Smith, 1999). Late in 2001, a more elaborate water quality monitoring system was installed at Stony Brook which measures pH, specific conductance, turbidity, temperature, and dissolved oxygen. Data from several additional continuous monitoring stations is anticipated to be accessible on the Internet by late 2002.

Data Management, Interpretation, Reporting, and Review

The monitoring and quality-assurance data were entered into a database, maintained by the CWD as part of this study, that enables the CWD analyze, track, and report changes in water quality efficiently. Monitoring was conducted by CWD staff with technical support from the USGS. USGS methods and protocols were used in the program so that results may be compared to baseline data collected by the USGS during water year 1998. This report was reviewed by a Technical Advisory Committee that includes members from the Cambridge academic community and a Watershed Advisory Committee composed of representatives from Cambridge, Waltham, Weston, Lexington, and Lincoln.

The CWD also conducts special investigations of water-quality-related problems and situations within the source area. Such investigations may include intensive monitoring at present water-quality-monitoring stations where increasing trends in contaminant loading have been noted, monitoring at locations where a known disturbance is taking place, and monitoring to assess the effectiveness of new management practices or infrastructure. These investigations frequently require analysis of a variety of constituents and water- quality related properties.

Table A-1 Water Quality Monitoring Schedule

Event Sites (3 times a year)

Continuous (bottles)	Partial (pipes/streams)
7	7
Discharge	Discharge
Temperature	Temperature
Conductance	DO
Turbidity	pH
Color	Conductance
Nutrients	Turbidity
Metals	Color
Ions	Nutrients
	Metals
	Ions
	Fecal Coliform

Primary Streams	freq.	Secondary Streams	freq.
10		6	
Station Maintenance	monthly	Discharge	quarterly
Discharge	monthly	Temperature	quarterly
Temperature	monthly	DO	quarterly
DO	monthly	pH	quarterly
pH	monthly	Conductance	quarterly
Conductance	monthly	Turbidity	quarterly
Turbidity	monthly	Nutrients	quarterly
Nutrients	monthly	Metals	quarterly
Fecal Coliform	monthly	Ions	quarterly
Color	quarterly	Fecal Coliform	quarterly
Alkalinity	quarterly		
Metals	quarterly		
Ions	quarterly		

Primary Reservoirs	freq.	Secondary Reservoirs	freq.
3		5	
Temperature	monthly	Temperature	quarterly
DO	monthly	DO	quarterly
pH	monthly	pH	quarterly
Conductance	monthly	Conductance	quarterly
Turbidity	monthly	Turbidity	quarterly
Nutrients	monthly	Nutrients	quarterly
Fecal Coliform	monthly	Metals	quarterly
Chlorophyll	monthly	Ions	quarterly
Secchi Disk	monthly	Secchi Disk	quarterly
Alkalinity	quarterly		
Metals	quarterly		
Ions	quarterly		
Color	quarterly		

Nutrients: TKN, TP, NO3-N, PO4-P(SRP)
Metals: Al, Mn, Fe, Na, Ca
Ions: Cl